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Pest Management Strategies for Longhorn Army Ammunition Plant and an Assessment of Aerial Radiography for Hazard Rating Pine Stands for Southern Pine Beetle Infestation

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PEST MANAGEMENT STRATEGIES FOR LONGHORN ARMY AMMUNITION PLANT AND AN ASSESSMENT OF AERIAL VIDEOGRAPHY FOR HAZARD RATING PINE STANDS FOR SOUTHERN PINE BEETLE INFESTATIONS.

by

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SOUTHERN PINE BEETLE INFESTATIONS

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ABSTRACT

Currently, sampling or hazard rating insects at military installations is limited. The use of aerial videography is a relatively new technology and is currently used for aerial surveys and is being developed for hazard rating for southern pine beetle. The purpose of this study was to apply existing sampling methods for various insects and disease at the Longhorn Army Ammunition Plant in Karnak, Texas and to test the effectiveness of aerial videography for hazard rating pine stands for southern pine beetle.

Based on field data, stands were generally rated as moderate for southern pine beetle; moderate to high infestations of pine tip moth occurred with little associated damage; and annosus root rot was not apparent in the stands. Fusiform rust was evident in the stands but little mortality occurred. Aerial videography at 1,000 feet AGL proved to be adequate for southern pine beetle hazard rating in this study. Because of the resolution of video, missions need to be flown at about 1000 feet above ground level (AGL) before individual trees in a dense forest may be discerned. Missions such as this should probably only be used for small stands, such as for the endangered red-cockaded woodpecker, *Picoides borealis*, stands, military installations, or tree farms. The project is stored as a GIS in the Arthur Temple College of Forestry GIS Lab.

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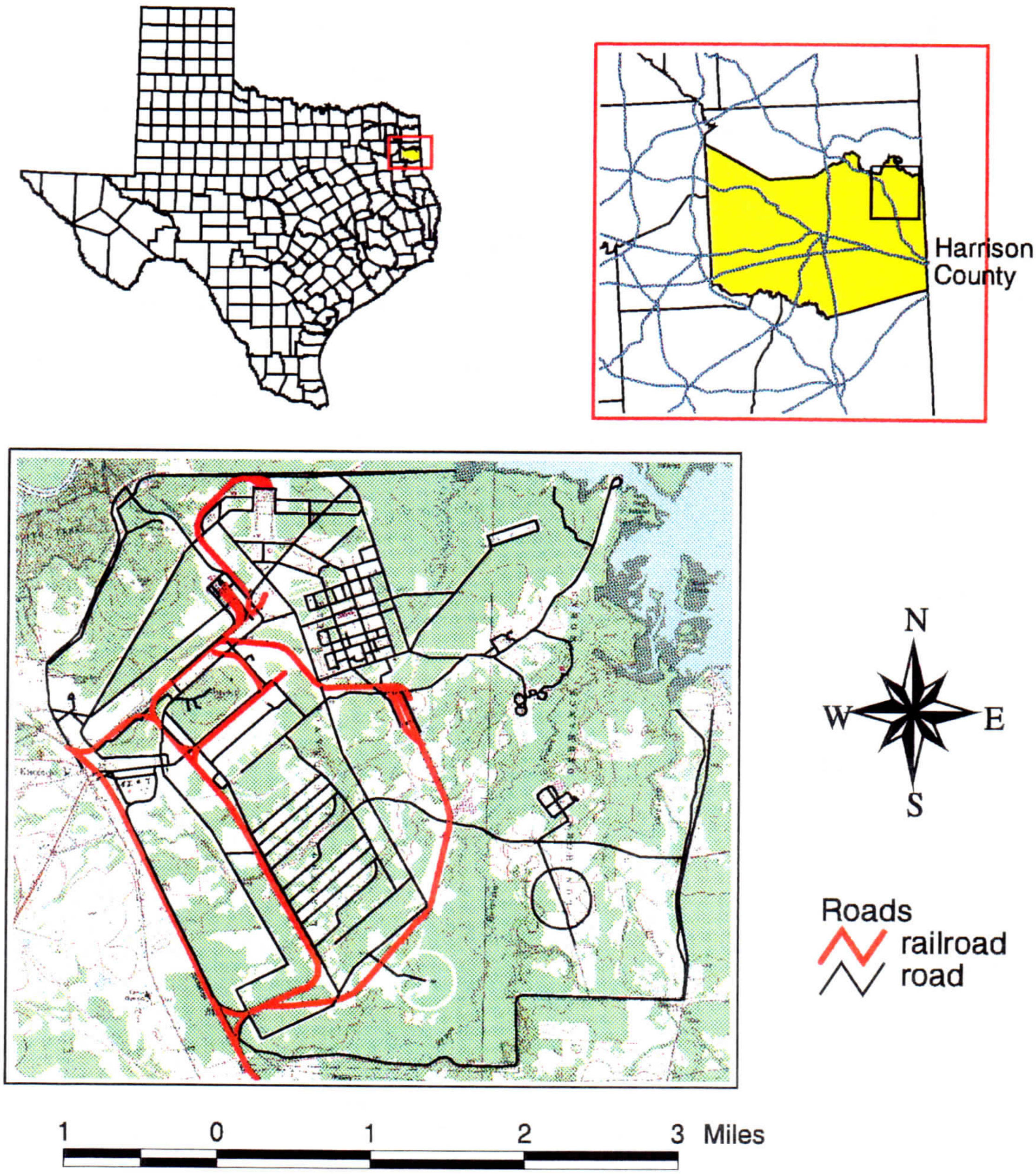
INTRODUCTION

The term "pest" is defined as an anthropocentric designation given to certain forest insects (and other organisms) when they adversely affect ecological, economic, and social values that we associate with forest and shade trees (Coulson and Witter, 1984). It is the social and economic values that we associate with an ecosystem, and the impact an insect has on these values, that determine whether or not we consider an insect a pest. Pest management, or population management, is, therefore, the attempt to maintain pest or potential pest populations at a tolerable level through various means. The management techniques used may vary depending on the ownership of the land (state, federal, private), and other constraints such as endangered species, management goals, etc. Methods of control are many, and should comply with the widely accepted concept of Integrated Pest Management (IPM), which is concerned with total forest management including pest management.

Longhorn Army Ammunition Plant (LAAP) is located on the southwest shore of Caddo Lake at Karnak, fifteen miles northeast of Marshall, in Harrison County, Texas (Figure 1). The installation covers 8317 acres, including 5930 acres of commercial forests. The climate is mild and temperate with an occasional frost and/or freeze in winter. The summers are relatively hot and humid. The growing season is on average 245 days. Summer and fall seasons frequently experience drought conditions. The average annual rainfall is 43.8 inches. Generally the topography is gently rolling to flat. The steepest slope is 30% at the extreme northwest side of the installation. The soils on this installation belong to the Forested-Coastal-Plains Problem Area and can be described as deep, acid, moundy, low in fertility, and mostly moderately drained. Both upland and bottomland forest types are found on the installation and cover about equal areas. The upland forests are composed of about 20% hardwood and 80% pine. Common associates include gums, oaks, and hickories. The bottomland forests consist of about 50+% hardwoods, dominated by black gum (*Nyssa sylvatica* Marsh.), sweetgum (*Liquidambar styraciflua* L.), oak (*Quercus spp.*),

Figure 1. Location map of Longhorn Army Ammunition Plant.



and baldcypress (*Taxodium distichum* (L.) Rich.). The pine component is less than 25%. Common associated species include willow (*Salix spp.*), ash (*Fraxinus spp.*), elm (*Ulmus spp.*), hackberry (*Celtis spp.*), and maple (*Acer spp.*). The open fields have been used for administrative purposes such as buildings, roads, and parking lots, etc. Loblolly pine (*Pinus taeda* L.), shortleaf pine (*Pinus echinata* Mill.), post oak (*Quercus stellata* Wangenh.), and sweetgum make up the majority of the timber production on the installation with the pines comprising approximately 70% of the total production. Other species are scattered throughout the installation, but comprise only a small portion of the forest production.

The installation site for the plant was selected on December 15, 1941. The land was purchased shortly thereafter from private owners who had used the land for farming and timber. Just prior to acquisition, the timber stands were cut very heavily and most of the merchantible trees were removed. Since that time the timber growing stock has been increasing. Most open areas were initially grazed by cattle, but have been reforested by either natural means or tree planting so that sawtimber stands now exist in most of these areas. The first commercial planting of pine took place in 1946 in Management Units 22 and 23, covering 55 acres. During the early sixties an extensive reforestation project was undertaken in which approximately 1200 acres of loblolly pine were planted in old pastures on the installation. In 1974 and 1975, about 166 acres of previously mowed area, most of it in the production areas, were planted. The first harvest was a pulpwood thinning made during 1958-1959 in Compartments I, III, and IV. Since then, thinnings and harvest cuts have been made on a regular basis throughout the area.

The plant, designated as a US TNT six-line special, was completed in 1943. The plant was classified as a standby installation in 1945 and changed to government-owned, government-operated status later that year. The plant remained in a standby status until 1952. Universal Match Corporation was the contractor-operator of Plant 2 facilities from 1952 until 1956. Their prime function was the loading, assembly, and packaging of pyrotechnic ammunition. Thiokol Corporation was the contractor-operator of the plant since 1953. They produced polysulfide polymer solid propellants. In 1963, they reopened Plant 2 facilities to load, assemble, and package pyrotechnic ammunition. The major forest fires that occurred in

1965 and 1979 were caused by testing of pyrotechnics, which burned approximately 450 acres of government-owned forest and 80 acres of privately-owned forest.

According to the Five Year Management Plan for the installation, the only problems with insects and/or diseases, that have been serious enough to warrant corrective action, were aphids on oak shade trees at the Administrative Area and bark beetles in pine timber stands. Aphids were treated with insecticidal soap or "Disyston" according to label directions. Pine bark beetles were either treated with "Lindane" according to label directions or the infested trees were cut and removed (Anonymous, 1993).

Study Focus

The main focus of this study was to determine the actual infestation and infection rates by pest insects and diseases and the hazard for the same within the pine component of the installation. The study also determined the effectiveness of using aerial videography to assess the hazard for the southern pine beetle (SPB), *Dendroctonus frontalis* Zimmermann. In the study, the pest organisms considered were: the southern pine beetle; Nantucket pine tip moth (NPTM), *Rhyacionia frustrana* (Comstock); fusiform rust, *Cronartium quercuum* (Berk.) Miy. ex Shirai f. sp. *fusiforme*; and annosus root rot, *Heterobasidion annosum* (syn. *Fomes annosus* (Fries) Karst.). Because of the trapping method used in the SPB study, many associated insects of importance were caught in the survey traps, allowing for inclusion in the study. These include reproduction weevils, *Hylobius* sp. and *Pales* sp.; the three species of *Ips* beetles (*Ips avulsus* (Eichhoff), *Ips grandicollis* (Eichhoff), and *Ips calligraphus* (Germ.)) of importance in this area; the ambrosia beetle, *Platypus flavicornis* (Fab.); and various borers, including *Monochamus* sp. Additional expected catches include the predators *Thanasimus dubius* (Fab.) and *Temnochila virescens* (F.). Hardwoods were excluded from the study because the upland study area did not have any apparent serious hardwood forest pests. The study area was directed at the more developed parts of the installation to use large scale aerial videography. The study area chosen was necessary because points obvious on the video that are shared on two frames are needed in order to mosaic the frames of the aerial video together. In this case, roads in the developed areas provided excellent reference points. Despite this limitation of study area, the results of the insect and disease studies may be used throughout the installation.

OBJECTIVES

The objectives for the study are:

1. Quantify pest hazards using stand inventory.
2. Quantify pest hazards using aerial videography.
3. Integrate aerial videography with ground-based pest hazard systems.
4. Develop a GIS database for the pest assessment of Longhorn Army Ammunition Plant (LAAP).

LITERATURE REVIEW

Remote Sensing

Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation (Lillesand and Kiefer, 1994). Developments in remote sensing might be outlined in terms of the three major components of the total system: the scene, the sensor system, and the processing system. The scene is the portion of the earth in the "view" of the sensor. The "observable" characteristics of the scene by the sensor are spatial, spectral, and temporal. The spatial characteristics are the geometric or cartographic features that allow us to determine position. The spectral characteristics are those that allow detection by electromagnetic (EM) energy to identify the quantity and possibly the quality of elements of the scene. The temporal characteristics are those dynamic characteristics which typify the earth surface environment as the quality, quantity, or position change through time. While we have little control over the scene, the more we learn of its characteristics the more we find there is to learn, and the better we can utilize remote sensing to gain understanding. Thus, part of our future application of remote sensing depends on our advancing knowledge of the scene through other senses and methods.

The sensor system is the data gathering device. It consists of the platform (aircraft or spacecraft, or on us, the eyes, ears, and nose), the sensor proper, and the data transmission component. It is designed to pick up the spectral characteristics of the scene at an appropriate scale resolution (spatial) and with appropriate frequency (temporal) to serve the needs of the problem. The dilemma is that there are limitless problems perceived by countless investigators. The designers, therefore, attempt to create a combination of sensors mounted on a variety of platforms with varying frequencies of over-flight in order to satisfy a broad range of user problems. Individual users are dependent on the system designer to make available the information-bearing dimensions of a given scene. The processing system may be considered to include the entire range of activities from receiving the raw data from the spacecraft or aircraft to the manipulation and display of data in the hands of the user. The first part of this stream of processes is beyond control of the user, administered by NASA or some other agency or firm. The user has a basic choice of computer photographic-like products or photographs, depending on handling capability, the nature of the job, and time constraints (Richason, 1978).

In the field of forestry, remote sensing by aerial photography has been used for several decades. Foresters were among the first to see the potentialities of black-and-white aerial photographs for forest management applications. Aerial photo interpretation has been used for classification of forest stands and types, survey of mortality and depletion, planning of reforestation, inventory of timber and other forest products, and assessment of property taxes (Barrett and Curtis, 1976). Among the special purpose applications of remote sensing, insect and disease damage assessment is the most studied (Leckie, 1985). Forest managers concerned with forest protection problems began using color and false-color transparencies before any other group of foresters. Now they benefit by the added dimension of color because of recent improvements in aerial color films and prints.

Color photography permits the natural resource specialist to make many more distinctions and to learn more about the environmental scene than is possible by interpreting shades of gray from panchromatic prints. For example, a photo interpreter can seldom separate more than 20 shades of gray on a black-and-white picture, whereas a trained color specialist can discriminate between 20,000 hues, values and chromas. Before 1945, no large-format color pictures were available for serious study. Color films then had low sensitivities (American Standards Association 10 to 32), and lenses on aerial cameras were seldom color corrected. Reconnaissance-type color films were developed during World War II in widths to 252 mm (9½ inches), sensitivities were increased to about ASA 40, and a false-color rendering film was developed (originally designated Kodak Camouflage Detection Aero Film).

Since 1960, substantial improvements in lenses, cameras, and films have resulted in color aerial photographs with good color fidelity and stability (Heller, 1971). In addition to providing more accurate results, the analysis of false-color infrared photography required less interpretation time than black-and white photography. Considering high labor costs, this factor is extremely important, particularly when salaries dominate the cost of large survey jobs. When interpreting color or false-color photos, the interpreters ponder less over difficult decisions, can more quickly recognize image characteristics, and more rapidly determine the species composition. Consequently, with this combination of advantages, the interpreter is far less likely to experience fatigue. Since the accuracy of interpretation decreases rapidly as fatigue increases, the total gain when using color or false-color photos instead of conventional black-and-white photos, particularly on large projects, is tremendous (Olson 1971). Since the film is always exposed through a yellow or orange filter (equivalent to a Wratten 12 or 15), much of the scattering effect of the atmosphere is eliminated. For the same reason, false-color film can be used at higher altitudes than color film (Heller, 1971).

Aerial photo interpretation provides a feasible means of monitoring many of the world's forest conditions. The airphoto interpretation process for tree species identification is generally more complex than for agricultural crop identification. A given area of forest land is often occupied by a complex mixture of many tree species, as contrasted with agricultural land where large, relatively uniform fields are encountered (Lillesand and Kiefer, 1994). Timber type differentiation is one of the most useful attributes of false-color film (Heller, 1971). For vegetation types occurring in the California Coast Range, Lauer (1969) showed that false-color infrared photography provided an image analyst with significantly more information on vegetation types than conventional black-and-white panchromatic photography, especially when attempting to locate and identify those forest types having similar image characteristics. In the infrared wavebands, there is a strong reflectance from deciduous trees but lower reflectance from coniferous trees. Thus, both infrared black and white film and infrared color film can be used to make broad distinctions between deciduous and coniferous trees (Barrett and Curtis, 1976).

Data from spectrophotometric analysis indicate that most angiosperms (hardwoods) reflect four to five times more energy in the near infrared (0.7 to 0.9 micrometers) than in the visible portions of the spectrum (0.4 to 0.7 micrometers). This high reflectance causes most deciduous foliage to appear red to magenta on Aerochrome Infrared Film. Since chlorophyll is transparent in the infrared region, other reasons for this high infrared reflectivity have been considered (Heller, 1971). According to Myers et al. (1970), the mesophyll portion of an angiosperm leaf has a large number of cell wall and air-space surfaces (spongy mesophyll cells) which reflect infrared radiation. In fact, by stacking many layers of leaves, greater IR reflectance is induced. No change in the visible part of the reflectance spectrum occurs as layers of leaves are increased. Palisade cells in angiosperms contain most of the chloroplasts and control the chlorophyll obsorption wavelengths at 0.38 micrometers and 0.65 micrometers; chloroplasts also contribute to the green peak at 0.55 micrometers. Pigment absorption from the palisade cells stabilizes the reflectance pattern so that additional leaf layers do not increase visible reflectance levels in green (0.55 micrometers). The acicular needle shape, variable orientation to the sky, lack of spongy mesophyll cells, and compact shadow patterns of conifers also contribute to the lesser total reflectance in all wavelengths.

The response of color film to vegetation under stress is considerably different from that to healthy vegetation. Signs of induced stress in plants include lack of moisture, color changes in foliage, loss of leaves, and disease organisms. The nature of the stress and the morphological characteristics of the plant (angiosperms or gymnosperms) affect reflectance and, in turn, the response of color film. Color film has been particularly useful in detecting stress caused by such destructive agents as insects, diseases, and air pollution. Infrared color film response is a subject of considerable controversy and one in which a number of factors still remain unidentified. These factors influence reflectance from forest canopies. An early expectation was that false-color film would be a previsual detector of stress in all forest species. Careful experimentation has shown that this is now usually the case.

Ciesla et al. (1967) found false-color film superior to normal color because of the extreme haze conditions prevalent in southeastern United States. The false-color photos are taken at a scale of 1:6000 and provide good discrimination between conifers and hardwoods and the healthy and infested pines.

However, stress symptoms in conifers show up as early on normal-color film as on false-color film, because by then the symptoms are also visible to the eye (Heller, 1971). Although damaged vegetation may be detected, it is extremely difficult to find out the causes of the damage from aerial photographs alone (Lo, 1986). Murtha (1978) suggested three approaches to the problem: the use of *a priori* knowledge, photo-keys, and enhancement techniques that should be combined together for the best results to identify the damage syndrome. The damage may be the result of an environmental stress, such as air pollution (sulfur dioxide) or a biotic stress, such as insects. They do exhibit differences in damage characteristics as revealed by normal color and color infrared photography at scales between 1:1,000 and 1:4,000.

Finally, in the assessment of the impact of the damage, five approaches are generally used: (1) counting the individuals affected; (2) delineating the aerial extent of the damage; (3) multiplying the affected area by ground surveys of crop production estimates to obtain a damage volume estimate; (4) stratifying the area into damage intensity levels; or (5) multiplying the area of damage intensity levels by predetermined volumes to get stratified loss volume. For example, the moisture stress induced by a bark beetle (*Dendroctonus ponderosae* Hopk.) on ponderosa pine (*Pinus ponderosa* Laws.) in the Black Hills of South Dakota causes the foliage to change color about 8 months after insect attack. As less water reaches the foliage, needles gradually change color from green to yellow, to orange-yellow, and finally to reddish-orange; this last color change usually occurs 12 to 14 months after the insect attack (Heller et al., 1959). Populations of the southern pine beetle build up quickly, because this insect may have four to seven generations per year. Because of the dynamic buildups of beetles and associated tree killing, aerial sketch-mapping has become a routine tool to assess the damage by this insect. *Fomes annosus* (Fr.) Cke. is a serious disease in the United States on which some remote sensing studies have been carried out. The effects of *Fomes annosus* on conifers resembles that of bark beetle infestation and dying trees and must be checked on the ground to conclusively identify the causal agent.

When coniferous needles become desiccated, the tightly packed cells and the lack of air spaces reduce the likelihood of collapse or shrinkage as is the case for deciduous plants. In fact, the amount of near infrared reflectance drops only slightly in coniferous needles when measured by a spectrophotometer, but when a physical disturbance - such as desiccation - occurs, visible reflectance always increases. This difference may partially explain why color infrared film has not been as successful as a previsual sensor. However, as previously stated, infrared color can be used under more severe atmospheric conditions than color film, and the false-color contrasts are often stronger and easier to separate by inexperienced photo interpreters. In beetle-killed trees, yellowish trees appear white to pink on color IR film, yellow-red trees appear bright yellow, and old dead graying trees with no needles and which are difficult to detect on color film appear greenish on infrared color film.

Angiosperms react differently. The cell structure of their leaves differs from coniferous needles by having a spongy mesophyll with air spaces. Under conditions of stress, the leaves become smaller, with more densely packed cells, thicker cell walls, and increased concentrations of cell sap. These changes tend to reduce IR reflectance. From infrared films of cereal crops in California, Colwell (1956) was able to detect rust in wheat before visual signs appeared. Manzer and Cooper (1967) had similar success with late blight on potatoes in Maine; here, the disease-affected plants were much darker than healthy plants. To date, no one has been able to detect stress in hardwood forests on infrared color films as a darkening of foliage. This lack of image darkening may be confounded by the intricate shadow pattern of hardwoods and mixture of many deciduous species, each with varying reflectance characteristics. However, when foliage discoloration occurs, infrared color film is useful to detect stress in hardwoods for the same reasons given for conifers - the greater color contrast and better haze penetrating qualities, not because of changes in IR reflectance.

The method of identification of tree species from aerial photographs was developed by Sayn-Wittgenstein (1961, 1978) who advocated the use of morphological characteristics of trees, such as crown shape, branching habit, and foliage characteristics for identification clues. This approach is believed to be more objective than the use of indirect indicators such as topography, drainage, aspect and association, which are useful but not always reliable. The success of this approach is largely determined by the scale of photography because morphological characteristics of trees become progressively less distinctive as the scale is decreased until they are inseparable from photographic tone, texture, and shadow pattern (Lo, 1986). On photographs at extremely large scales (such as 1:600), most species can be recognized almost entirely by their morphological characteristics. At this scale, twig structure, leaf arrangement and crown shape are important clues to species recognition. At scales of 1:2400 to 1:3000, small and medium branches are still visible and individual crowns can be clearly distinguished. At 1:8000, individual trees can still be separated, except when growing in dense stands, but it is not always possible to describe crown shape. At 1:15,840, crown shape can still be determined from tree shadows for large trees growing in the open. At scales smaller than 1:20,000, individual trees generally cannot be recognized when growing in stands, and stand tone and texture become the important identifying criteria (Lillesand and Kiefer, 1994).

The most useful morphological characteristics from the vertical aerial photographic point of view are crown shapes, texture and branching habits. Tree species can be identified on aerial photographs though the process of elimination. The first step is to eliminate those species whose presence in an area is impossible or improbable because of location, physiography, or climate. The second step is to establish which groups of species do occur in the area, based on a knowledge of the common species associations and their requirements. The final stage is the identification of individual tree species using basic photo interpretation principles. The photographic characteristics of shape, size, pattern, shadow, tone, and texture are used by interpreters in tree species identification. Individual tree species have their own characteristic crown shape and size. Some species have rounded crowns, some have cone-shaped crowns, and some have star-shaped crowns. Variations of these basic crown shapes also occur. In dense stands, the arrangement of tree crowns produces a pattern that is distinct for many species. When trees are isolated, shadows often provide a profile image of trees that is useful in species identification. Toward the edges of the photo, relief displacement also affords somewhat of a profile view of trees. Tone in aerial photographs depends on may factors, and is not generally possible to correlate absolute tonal values with individual tree species. Relative tones on a single photograph, or a strip of photographs, may be of great value in delineating adjacent stands of different species. Variations in crown texture are important in species identification. Some species have a tufted appearance, others appear smooth, and still others look billowy (Lo, 1986).

Aerial photo interpretation is used extensively for "timber cruising." The primary objective of such operations is to determine the volume of timber that may be harvested from an individual tree or (more commonly) a stand of trees. To be successful, aerial photo timber cruising requires a highly skilled interpreter working with both aerial and ground data. Photo measurements on individual trees or stands are statistically related to ground measurements of tree volume in selected plots. The results are then extrapolated to large areas. The photo measurements most often used are (1) tree height or stand height, (2) tree-crown diameter, (3) density of stocking, and (4) stand area. The height of an individual tree, or the mean height of a stand of trees, is normally determined by measuring relief displacement or image parallax. A very simple device for measuring parallax is the parallax wedge. It consists of a transparent sheet of plastic on which two converging lines or rows of dots (or graduated lines) are printed. Next to one of the converging lines is a scale that shows the horizontal distance between the two lines at each point. Consequently, these graduations can be thought of as a series of parallax bar readings. The wedge is positioned so that one of the converging lines lies over the left photo in a stereopair and one over the right photo. When viewed in stereo, the two lines fuse together over a portion of their length, forming a single line that appears to float in the stereomodel. Because the lines on the wedge converge, the floating line appears to slope through the stereoscopic image.

The task of measuring tree-crown diameters is no different from obtaining other distance measurements on photos. Ground distances are obtained from photo distances via scale relationship. The process is expedited by the use of special purpose overlays similar to dot grids. Overlays are also used to measure the density of stocking in an area in terms of the crown closure or percentage of the ground area covered by tree crowns. Some measure of the number of individual crowns per unit area may also be made. The accuracy of these measurements is influenced by such factors as the film-filter combination used for photography, the season of photography, and the amount of shadow in the photographs (Lillesand and Kiefer, 1994). Foresters can use photographic tone, texture, and color to identify different tree stands and make precise measurements of tree height, crown diameter or stand density. Tree height is closely related with tree volume and stand volume and can be measured on photographs in a number of ways.

Measurement of shadows, measurement of parallax, and measurement of relief displacement on single large-scale vertical or oblique photographs are some of the methods used.

Tree shadow measurements are normally made with a micrometer scale consisting of a finely graduated series of short lines, one of which is matched with each shadow visible on the air photograph. Measurement of crown diameter can be made by either micrometer or dot type crown wedges. The micrometer wedge consists of two converging lines calibrated to read intervening distance to the nearest thousandth of an inch. The dot type wedge usually consists of a series of dots differing in diameter by .0025 in. It is laid alongside the image and moved until the dot that just matches the size of the crown is identified. The dot images may also be moved over the crown until the appropriate size which covers the crown is found. The accuracy of crown measurement is largely dependent on the scale of the photographs. The error may be 3-4 feet with either kind of measuring device on photographs of 1:12000 scale. Transparent dot templates are probably the most widely used area measuring instruments in forest inventories made from aerial photographs. The density of dots in a template varies from 1-65 per square inch depending on the intensity of the survey and the scale of the maps on photographs used. The ratio of dots in a given class to dots in the entire tract gives the proportion of the tract occupied by that class. Crown coverage or crown closure, expressed as a per cent of the area covered by trees on the image is often considered a better estimate of stand density than crown count. A transparent overlay carrying a dot grid, fine enough to place 25-60 dots in the forest stand is placed over the image. The number of dots falling on tree crowns is then compared with the total number of dots in the stand area. These elementary devices for the measurement of size and area can now be replaced (at a cost) by automated scanning equipment. If very large areas are to be studied, such equipment is essential for data to be available within a reasonable period of time (Barrett and Curtis, 1976).

For most photogrammetric activities, one form of ground reference data is essential-ground control. Ground control refers to physical points on the ground whose ground positions are known with respect to some horizontal coordinate system and/or vertical datum. When mutually identifiable on the ground and on a photograph, ground control points can be used to establish the exact spatial position and orientation of a photograph relative to the ground at the instant of exposure. Accurate ground control is essential to virtually all photogrammetric operations because photogrammetric measurements can only be as reliable as the ground control on which they are based. Measurements on the photo can be accurately extrapolated to the ground only when we know the location and orientation of the photograph relative to the ground at the instant of exposure (Lillesand and Kiefer, 1994).

Aerial Videography

The use of aerial videography is very new compared to aerial photography. Some advantages of aerial videography over still photography are: 1) imagery is available immediately, a particularly advantageous attribute for pest and disaster surveys, 2) the operator can view "live" imagery on a monitor in the aircraft during acquisition, 3) it permits voice annotations on the audio track during the flight, 4) easy transfer from videotape to digital format for computer processing, 5) video is lower in cost than photography, 6) it improves the success rate of acquiring the desired coverage at a give point in time, 7) video can be taken in areas of low light or weather conditions, and 8) video may be used in foreign countries where aerial photos and processing may be difficult to acquire (Myhre, 1992). The first publication dealing with aerial videography, by Manzer and Cooper (1982), was concerned with the detection of potato disease. Hazard (1987) reported that aerial videography showed significant improvement in the spectral differentiation between some vegetation classes as compared with interpretation of National High Altitude Aerochrome infrared photography (NHAP). According to Nixon et al. (1985,1987), multi-band video is adequate for assessment of vegetation differences and conditions. Meisner (1986) concluded that video was effective for applications requiring a large scale but not full coverage and for applications requiring a large area of coverage with reduced resolution. Thomasson et al. (1988) states that the minimum scale for vegetation analysis by aerial videography should be 1:12000, and that 1:6000 or larger is better. The Forest Health Protection group of the US Forest Service established a video remote sensing program after Lusch et al. (1987) found that color infrared aerial video could be used to delimit gypsy moth defoliation and rank its severity (Linden et al., 1996).

Geographic Information Systems (GIS)

Development of digitizing and photogrammetric instruments along with the mathematical theories to link these instruments with computers in the fifties laid the groundwork for GIS development in the sixties. The Canadian Geographic Information System (CGIS), developed in the sixties, was the first GIS and was developed by the State of Minnesota and Environment Canada (Marble, 1984; Sims, 1995). During this first generation of GIS's, the parent computers were mainframes. During the second generation, GIS's were minicomputer based, the third were workstation based, the fourth generation were workstation and PC based and the fifth are server, workstations and PC based (Antenucci, 1993). These systems were developed for local, regional, and national data sets and tended to be large in scope. While contributing to the development of modern GIS's, many of the early GIS's were marginal successes or outright failures. As late as the seventies, these GIS's were plagued by poor design and performance problems (Marble 1984). Many factors in the United States including government involvement, demand on natural resources, software development, and hardware improvements have made the proliferation of very capable GIS's. GIS's are now inexpensive enough and user friendly enough for local government, businesses, and smaller educational institutions to obtain and utilize. GIS technology is for the first time available to most educational departments which can specialize their use in many fields. Policy planning, master planning, inventories, resource analyses, and regulation and control of parks are all GIS applications (Cho, 1991).

During the eighties and nineties, more government branches and private corporations made GIS integration a goal if not a mandate. In 1990, Washington law required all cities and counties to carry out comprehensive planning to manage urban growth within this state (Newcombe, 1994). Many state, county, and municipal managers turned to GIS to integrate data and conduct the analysis. Although planners have not been known for their use of GIS, because they don't need the accuracy of other GIS users, they have benefited from GIS's ability to pull data from many sources (Newcombe, 1994).

The key components of GIS are as follows: 1) Collection, input and correction are the operations concerned with receiving data into the system, including manual digitizing, scanning, keyboard entry of attribute information, and on-line retrieval from other database systems. It is at this stage that a digital map is first constructed. The digital representation can never be of higher accuracy than the input data, although the mechanisms for its handling will frequently be capable of greater precision than that achieved during data collection; 2) Storage and retrieval mechanisms include the control of physical storage of the data in memory, disk or tape, and mechanisms for its retrieval to serve the needs of the other three components (Martin, 1996). In a disaggregate GIS (Webster, 1988), this data storage may be physically remote from the rest of the system, and may meet the database requirements of other, non-geographic, data-processing systems. This module includes the software structures used to organize spatial data into models of geographic reality; 3) Manipulation and analysis represents the whole spectrum of techniques available for the transformation of the digital model by mathematical means. These are the core of a GIS. A library of data-processing algorithms is available for the transformation of spatial data, and the results of these manipulations may be added to the digital database and incorporated in new visual maps. Using these techniques, it is possible to deliberately change the characteristics of the data representation in order to meet theoretical requirements. It is equally possible to mishandle or unintentionally distort the digital map at this stage; 4) Output and reporting involves the export of data from the system in computer- or human-readable form (Tomlinson, 1984). It is at this stage that the user of a digital map database is able to selectively create a new analog map product by assigning symbols to the objects in the data model. The techniques involved here include many of those of conventional cartography, which seeks to maximize the amount of information communicated from the map maker to the map reader. The nature of the digital model at this stage will have a major impact on the usefulness of any output created.

The fundamental classes of operations performed by a GIS have been characterized as a 'map algebra' (Tomlin and Berry, 1979; Berry, 1982, 1987; Tomlin, 1991) in which context primitive operations of map analysis can be seen as analogous to traditional mathematical operations. A distinction is then made based on the processing transformation being performed. These 'classes of analytical operations' are divided into reclassification, overlay, distance/connectivity measurement and neighborhood characterization, which are independent of raster and vector representations of the data: 1) Reclassification operations transform the attribute information associated with a single map coverage. This may be thought of as a simple 'recolouring' of features in the map. For example, a map of population densities may be reclassified into classes such as 'sparsely populated' or 'overcrowded' without reference to any other data; 2) Overlay operations involve the combination of two or more maps according to Boolean conditions (e.g. 'if A is greater than B and A is less than C'), and may result in the delineation of new boundaries. In such cases, it is therefore essential that the spatial and attribute data are a correct representation of the real-world. An example would be the overlay of an enterprise zone on to a base of census wards. This would be appropriate for determining the ward composition of the zone, but may not allow an accurate estimate of the population falling within it, as there may not be exact coincidence of the boundaries. Thus, the operation is only appropriate if the intended interpretation of the data is meaningful; 3) Distance and connectivity measurement include both simple measures of interpoint distance and more complex operations such as the construction of zones of increasing transportation cost away from specified locations. Some systems will include sophisticated networking functions tied to the geographic database. Connectivity operations include, for example, viewshed analysis which involves the computation of intervisibility between locations in the database; 4) Neighborhood characterization involves ascribing values to a location according to the characteristics of the surrounding region. Such operations may involve both summary and mean measures of a variable, and include smoothing and enhancement filters. These techniques are directly analogous to contextual image-classification techniques to be found in image-processing systems (Martin, 1996).

Cho (1991) identified four attributes which set GIS's apart from other systems: 1) GIS integrates spatial and other kinds of information within a single consistent system; 2) GIS incorporates innovative display and manipulation of digital data; 3) GIS allows otherwise unrecognizable relationships between geographic entities to be better understood; 4) and GIS allows access to a variety of administrative data with geographic attributes.

Southern Pine Beetle

The southern pine beetle (SPB), *Dendroctonus frontalis* Zimmermann, is an important insect to be considered in management of loblolly and shortleaf pine in the Gulf Coastal Plain. In 1985, it was estimated that SPB infested 200,000 acres in the southeastern United States, predominantly in Texas, Louisiana, and Mississippi. It was also estimated that in Texas alone in 1985, pines killed by SPB on 80,000 acres were worth about $33 million to timber and other resources (Alcock, 1985). From 1991 to 1992, there was a 33% increase in acreage affected by SPB, and there was a 58% increase in the number of infestations. Its range includes an area in North America south of a line from New Jersey to central Arizona to northern Nicaragua. SPB is a multivoltine species with a complete metamorphosis consisting of the egg, larval, pupal, and adult stages (Coulson and Witter, 1984). The time it takes to reach the adult stage from the egg ranges from 26 to 54 days, depending on the season. In the northern parts of its range (North Carolina, Virginia), SPB may have as few as three generations per year while as many as seven to eleven generations per year occur in the southern parts of its range (Texas, Honduras) (Coulson and Witter, 1984, Thatcher, 1960). Temperature is probably the biggest factor influencing the rate of development of SPB. Parasites and predators of the beetle throughout its different life stages as well as competition for food are also major factors that influence the beetle (Dixon and Payne, 1979, Birch et al., 1980).

A beetle spot (a group of trees which beetles have infested) usually begins with a wounded or stressed tree. A wound may be the result of wind snap (though seldom), man made wounding, or, most commonly, lightning strikes. Once the tree is wounded, it releases a host volatile called alpha-pinene into the air. This may attract female southern pine beetles which bore into the phloem of the tree (Birch et al., 1980), releasing frontalin (an aggregating pheromone) in the process. The odor of frontalin mixed with alpha-pinene has a synergistic effect which attracts more females and some males. This second group may attack in the hundreds or thousands, numbers sufficient to overcome the tree's defensive system of resin production. Once under the bark, the females mate and create S-shaped "galleries" to deposit eggs. The males then produce another pheromone called verbenone in small amounts, which is yet another attractant. After a period of time when crowding becomes a factor, the males begin to produce high amounts of verbenone and other inhibiting compounds, which have an anti-aggregating effect on the beetles. This causes the beetles to begin "switching," which is the act of flying to other uninfested trees that are located in proximity to the pheromone source. The aggregation pheromones induce the flying beetles to land and initiate attacks on these adjacent pines. This process may accelerate as beetles emerging from the trees within the back of the spot are attracted to uninfested trees at the leading edge, resulting in rapid expansion of the infestation.

Detection of a spot is a very important part of the pest management system for SPB. Surveys are classified according to their purpose as: (1) detection surveys, (2) biological evaluations, (3) loss or damage surveys, or (4) pest control evaluations. The surveys can be quantitative or qualitative, and the procedures used to collect the data depend on the type of forest situation being sampled, the type of survey being conducted, and the intended use of the data being collected. There are three field operations involved in locating and suppressing SPB. These are:

Aerial detection surveys - these are used to locate infestations, or spots, over a large area usually from a fixed wing aircraft

Ground checks - necessary to determine if SPB is the cause of the damage and if there is need for immediate control.

Control - those measures taken to alleviate the problem (Thatcher et al., 1980).

Through the aerial survey, the direction of spread and, to an extent, the age of a spot can be determined. Viewed from the air, the infestation appears as a group of red- and yellow-crowned trees. It can be estimated that bare crowned trees were killed long ago and no longer contain SPB. In front of these (in relation to the direction of the movement of the spot) are red crowned trees, which probably do not have SPB in them any more (except during the winter months). In front of these are yellow-crowned trees which are those that were only recently attacked and usually contain SPB larvae, pupae or new brood adults. Newly attacked trees cannot be distinguished from uninfected trees from the air because their crowns are still green. Although inactive spots (those with no currently infested or yellow-crowned trees) may not even be reported by the aerial survey crew, those spots with ten or more red- and yellow- crowned trees should be reported with a ground check priority. A spot will be given either a high, medium, or low priority for ground checking based on the color of the infested tree crowns, the estimated number and volume of the infested trees, and the threat to surrounding forests (Billings and Pase, 1979). The ground crew takes the information given them by the aerial crew and does a ground check. Ground checking is very important to determine the cause of damage and priority for control. Once the spot has been detected and verified, a control priority for the spot is assigned. The ground crew determines control priority using three criteria: 1) actual presence of SPB, 2) activity of the spot, and 3) capability of spot expansion, determined by the presence of fresh attacks and adjacent uninfested pines. There are three levels of priority for control:

High-priority spots - those spots with the largest number of SPB-infested trees, particularly in dense stands. These should be treated first, and the preferred treatment is to salvage and utilize the affected trees. There can be very little delay in action on these spots because of the volatility of the situation that they create.

Medium-priority spots - should not be treated until all the high-priority spots have been treated.

Low-priority spots - rarely need treatment because, according to past experience, they usually die out by themselves.

The logic behind control of SPB "is based on knowledge of pest population dynamics, stand dynamics, an appraisal of impacts on resource values, and costs of application. Control tactics are planned procedures that are used to modify or regulate the distribution and abundance of a pest species" (Coulson and Witter, 1984). There are two general types of control: prevention or regulatory controls, which attempt to prevent introduction or to contain the pest, and cultural or silvicultural controls, which stress the management of stand characteristics. By design, any control tactic is supposed to affect reproduction, mortality, immigration, and/or emigration. Examples of control methods include:

biological control - includes augmentation of insect parasites, insect predators, avian predators, and diseases
chemicals - which include various pesticides applied to infested trees to reduce pest numbers
behavioral chemicals - include compounds which result in attraction or dispersal of airborne populations
utilization - involves harvesting of infested host materials
various mechanical procedures - which include felling infested hosts and burning infested hosts (Coulson and Witter, 1984).

With the exception of SPB, most forest pests that affect pine trees after the establishment stage do not or very infrequently demand direct control in forest situations. Control should be a year-round job with efforts increased in late spring through fall. Treatments in the winter and early spring are also important to help reduce the potential for spot initiation and subsequent development. Because of differing management goals, owner's opinions, access by heavy equipment, demand for beetle-killed timber and other factors, the form of control utilized will differ. The most commonly used methods for SPB are:

- Salvage - This technique can be considered economically feasible only when a large volume of wood is available. Prompt action is necessary to prevent spot enlargement and to get the best return on the sale of the infested trees.
- Cut and Leave - Attacked trees and healthy trees around the border of the spot are felled inwards towards the center of the spot to disrupt further spot expansion.
- Pile and Burn - This method is very seldom used. The trees are felled as in Cut and Leave and then piled in a central area to be burned.

- Chemical Control - If used properly, this technique can protect healthy trees, and kill pests in infested trees. Cost of application is small when compared to the value of the trees. Efficient application depends on the correct identification of the species involved, selection of appropriate trees to be sprayed, and the careful application of the insecticides. Trees which have been vacated by the SPB should not be sprayed because of the possibility of killing natural enemies of the beetles which have not yet left the trees. All of the chemicals registered for southern pine bark beetle control are toxic to other organisms, including humans. Once the chemical has dried on the tree, though, it presents little risk to humans or other mammals.
- Do Nothing - doing nothing is also a viable method of management when conditions allow or demand it.
- A new method of preventative control is the use of verbenone packets. These are polyethylene bags which contain small amounts of synthetic vebenone. They are attached to newly attacked pines and neighboring uninfested at about ten to twelve feet above the ground. This method is still being tested and requires EPA registration before it will be available for wide range use.

All of the above options are determined by site specific needs and the needs of the landowner or manager. However, a high priority spot commands a measure of urgency when determining and implementing any plan of action. Thus, a predetermined protocol for action may be suggested so that minimal timber losses may be incurred. Preventative management of the pine resource through such means as hazard rating to determine susceptibility, careful logging to avoid wounding the residual stand, and timely thinnings, is possibly the best method of prevention.

It can be said that hazard rating "can greatly improve the manager's ability to make SPB control decisions that are biologically and economically sound" (Mason, 1980). Hazard rating pines for SPB in Texas, according to the method proposed by Mason et al. (1981), is based on three field observations: 1) The pine basal area of the stand, 2) average stand height (or dbh), and 3) land form. Hazard rating may identify current or potential hazards. However, to be of use to the manager, "the rating system should permit the manager to identify the smallest land unit acreage on which the greatest loss due to SPB might be expected" (Mason, 1980). Information from the rating may be used by landowners/managers to select stands for early treatment to help reduce potential losses due to SPB. The information could also be used by the appropriate people to monitor the beetle. Hazard rating can provide landowners and managers with the information they need to protect their resource from what is, in such case, a pest. It gives a descriptive estimate of where the highest potential stands for attack are so that preventative measures can be taken before the beetles are allowed to become a pest problem.

Nantucket Pine Tip Moth

The Nantucket pine tip moth (NPTM), *Rhyacionia frustrana* (Comstock) (Lepidoptera: Oleuthreutidae), is a very important insect in the eastern US and in remote areas of the western US. NPTM was first discovered and studied on Nantucket Island, Massachusetts, where it caused severe damage to pine. Its range extends from Massachusetts to Florida and west to Texas. It was found in San Diego County, California, in 1971 and traced to infested pine seedlings shipped from Georgia in 1967. The moth has since spread north and east in California and is now found in San Diego, Orange, and Kern Counties. It has been similarly introduced into New Mexico (Berisford, 1987). NPTM is a threat to timber farms, especially Christmas tree farms, pine plantations, and to naturally-regenerated seedlings. Its more favorable hosts are loblolly, shortleaf, and Virginia pines, *Pinus virginiana* Mill. (Yates III et al., 1981). But when loblolly and shortleaf grow adjacent to each other, shortleaf pine is more seriously injured, even when they receive the same relative incidence of attack. The NPTM is a serious problem in the East, especially in North Carolina, where high quality timber and Christmas trees are grown. Elsewhere its presence is well known but the damage is not as severe. Forestry practices which aim to maximize fiber and timber production have resulted in the establishment of increasing acres of pine plantations. These plantations are susceptible to tip moths during early growth (ages 1-5 years) and populations of tip moths and numbers of damaged tips vary according to site/stand factors and tree species (Sun, 1990).

Nearly all species of native and exotic pines that grow in the eastern half of the United States are attacked by the Nantucket pine tip moth. The only exceptions are longleaf and eastern white pine, *Pinus strobus* L. Slash pine, although quite resistant, is also occasionally attacked. Certain species are preferred by the Nantucket pine tip moth in different parts of the United States. In California, most hard pine species have been found to be suitable hosts, but the favored host is Monterey pine, *Pinus radiata* D. Don. In the South and Southeast, the favored hosts are loblolly and shortleaf pine. Pitch, *P. rigida* Mill., Virginia, and Scotch pine, *Pinus sylvestris* L., appear to be favored in New England and the Middle Atlantic States. And shortleaf pine is favored in the Central States (Yates III et al., 1981). Pine species that have multinodal growth in a single season are especially favorable hosts because when shoots are killed by tip moth larvae the tree responds by producing new succulent shoots from the base of the dead shoot. When the adult moths emerge they find a new crop of shoots for egg laying. Repeated crops of new shoots can support an increasing population of tip moths throughout the spring and summer (Meeker, 1987).

The Nantucket pine tip moth is most damaging to pine plantations and to wild pine seedlings in open areas. It poses an ever-increasing problem because of forestry trends that favor the establishment of large areas of pine plantations. Tip moths may also be particularly damaging to pine seed orchards because they kill female flowers and conelets and often reduce the survival of outplanted grafted stock during seed orchard establishment (Ebel et al., 1975). Direct attacks on shortleaf pine conelets often cause losses of 30 percent or more.

Indications of tip moth damage are browning, curling and dieback of infested tips. Yates (1960) classified NPTM damage into four categories including: 1) deformation of host tree; 2) loss or retardation of height growth; 3) reduction of cone crops; 4) mortality of infested trees under severe instances. In addition, tip moth damage reduces the aesthetic (axiological) value of pines used for ornamental purposes and Christmas trees (Lewis, 1976). Trees less than 4.5 meters in height are most severely injured by tip moth attack, although larger trees have been known to be heavily infested (Lewis, 1976).

Weyerhaeuser Corporation data on pines grown on short rotations in Arkansas and Oklahoma indicates that tip moth damage can reduce pulpwood production by one to two cords per acre (Flavell, 1974). The overall effects of tip moth attack are serious tree deformation and growth loss over a long period of time. And though corresponding infestation levels required to cause such effects are not thoroughly understood (Stephen, 1984; Meeker, 1987), economic thresholds governing control practices are being developed.

In a study comparing height growth between trees treated for tip moth and untreated trees, Lashomb et al. (1978) found that treated trees averaged twice the height of untreated trees after three years. For three successive years, seedling growth was reduced by 0.15 meters each year due to NPTM attack, as reported by Wenger (1955). According to Merkel (1955), after one growing season in the Piedmont area of South Carolina, trees unprotected from tip moth attack averaged 0.13 meters in lost height growth compared to protected trees. And Neel (1959) found that when terminal tip moth attack was completely checked, uninfested loblolly seedlings averaged 0.39 meters greater height than unprotected seedlings. Simulated tip moth attacks also reduced root growth of shortleaf pine seedlings by more than 50% (Fox and King 1963, Wick 1985). Loss of form is particularly important on ornamental and Christmas trees, which become virtually worthless if tip moth attacks are not controlled (Coyne and Lott, 1976; Sun, 1990).

The NPTM overwinters as a pupa in the terminal except at the extreme northern part of its range where it overwinters in the ground (Yates et al., 1981). When the temperature warms up, adults emerge, mate, and females lay eggs on the most recent shoots and conelets. Eggs may take as long as thirty days in cold weather and as few as five to ten days in the summer to hatch. These newly-hatched larvae feed only on the surface of the new shoots, causing only shallow injury, or they may bore into the needle fascicles. They later move to the shoot tips and build a protective web at the base of the buds. This web is found in the axil formed by the developing needle and the stem. Later, a more prominent indication of infestation is webbing at the shoot tips and accumulated resin and fecal material within this webbing. This is a sign that the larvae are boring into the bud or stem tissue. Such feeding, which severs the conductive tissue and causes death of the shoot, takes about three to four weeks until the larvae are fully grown. Soon, tips of infested shoots die and turn brown, becoming quite noticeable from a distance.

Shortleaf pine is quite susceptible to conelet damage by NPTM (Yates III et al., 1981). First indications of NPTM attack of conelets are the presence of boring frass on the conelet surface and the appearance of dead conelets. Pupation occurs in the cavities formed by the feeding larvae. The insect may complete five generations per year, depending on location and weather conditions. Usually, two generations occur in the northern part of its range, three generations in middle of its range, and four to five generations may occur in the southern extent of its range. Here, where there are five generations per year, the first occurs in early March, the second in early June, the third in early July, the fourth from mid August to September, and the fifth in November. Only the first generation of NPTM causes significant mortality by feeding directly in and on the flowers and conelets. However, minor conelet damage may occur due to the last generation of NPTM in the fall (Ebel et al., 1975). Trees are usually only susceptible to NPTM until they reach a height of about ten feet and when the canopy is still open. Trees are usually not killed by attacks, however, their growth can be stunted and their normal or expected shape can be greatly altered with the occurrence of the short, bushy appearance that describes many attacked and damaged trees. In areas where NPTM is most damaging, every shoot may be killed, preventing most vertical growth (Yates III et al., 1981).

Habitat characteristics, both site and stand factors, qualitatively and quantitatively influence the amount of tip moth damage (Meeker, 1987). The more suitable the host trees are to the site, generally the less severe the damage (Wakeley, 1928, Yates, 1960). Shading and natural regeneration of host trees, and increased levels of competing vegetation, reduce tip moth incidence (Yates, 1960, Miller and Stephen, 1983). Rate of tip moth infestation is directly related to degree of intensity of site preparation, with greatest infestations occurring on sites most intensively prepared (Hertel and Benjamin, 1977, White et al., 1984, Berisford, 1987). Open-grown stands have higher infestation rates compared to those grown under some type of cover (Berisford and Kuhlman, 1967, Lewis, 1976). Monoculture regeneration may decrease the availability of alternative hosts and food sources, such as pollen and nectar, for natural enemies. For example, it has been shown that tip moth parasitism by Hymenoptera is lower in loblolly pine plantations where competing vegetation has been treated with herbicides (Sun, 1990). Wakeley (1928) states that host trees grown in dense stands suffer less tip moth damage. Though White (1982) concluded that "those areas best suited for pine growth are most susceptible to NPTM attack."

White et al. (1984) investigated a variety of site/stand characteristics in developing empirical hazard models for Nacogdoches County, Texas. Site preparation intensity, site index, tree age, tree height, depth of the A horizon times the soil texture code, and soil texture at 61 centimeters were significant factors in classifying plantations as either low or high hazard to tip moth attack. Wilson (1984), in a validation study of the models by White et al. (1984), for Jasper and Newton Counties as well as Nacogdoches County, Texas, incorporated depth of soil profile of active soil formation and number of trees per hectare as characteristics significantly affecting grouping of stands into either high or low hazard to NPTM. Wilson stated that sites suitable for best growth were highly susceptible during periods of high tip moth activity; whereas during low periods of tip moth activity, those sites exhibiting low growth potential were most susceptible.

In South Carolina, Hood (1986) also found site preparation intensity, site index, and depth to A horizon as well as soil calcium to be the most significant variables for predicting tip moth incidence. Intensive site preparation, low site index, shallow A horizon, and low soil calcium led to high tip moth infestations (Hood, 1986). Soil texture is a critical site factor, affecting soil moisture relations, rooting characteristics, and tree growth (Pritchett and Fisher, 1979). White (1982) found that risk of tip moth attack and damage increased with soil particle size in the B horizon, while Wilson (1984) found that probability of NPTM attack increased with finer textured A horizons. Both White (1982) and Wilson (1984) found that restrictions to rooting, including shallow A horizons, resulted in increased probability of NPTM attack. Meeker (1987) found that NPTM infestation rates in 1985 and 1986 increased with increased percentages of silt sized particles in the soil (A and B horizons combined).

The NPTM is the target of over thirty known species of parasites. It is also a food source for many predatory birds and insects. A parasitic wasp, *Campoplex frustranae* (Cushman), was brought to southern California from Georgia and has had very positive effects in the elimination of NPTM. Control by insecticides is not recommended except in seed orchards, nurseries, Christmas tree farms, and other intensively managed plantations, or on ornamentals. Several insecticides are registered for tip moth control, including azinphosmethyl, dimethoate, disulfoton, and trichlorphon. Some are applied to pine foliage and others, which are systemic insecticides, are applied to the soil. If foliar sprays are used and season-long control is desired, spraying may be necessary for each generation of NPTM. The spray should be directed at young larvae, which feed on the exterior of the shoot for several days. Eggs hatch 5 to 10 days after the peak of adult emergence. When cool weather follows peak adult emergence in early spring, spraying should be deferred for about 14 days. When systemics are used, they should be applied in late winter or early spring. Also, if pheromone traps are being used, whenever the first male is caught in a trap plus ten days is when chemicals should be applied (Stearns, 1953, Beal, 1958). However, there may be some confusion with this approach because there is a primary "false" flight. And sometimes, when chemicals are used, secondary pests such as scale insects may emerge as their predators are killed.

Proper cultural practices may also be used to minimize the damage done by NPTM. Those tree species that are most susceptible to NPTM should be planted only on sites for which they are well adapted. Marginal sites with poor moisture and nutrient conditions leading to low host productivity should be planted with a more suitable species such as longleaf pine, which is immune to Nantucket pine tip moth. Spacing trees closely and planting under an overstory may also help to reduce risk to trees (Yates III et al., 1981).

Encouraging rapid growth enables host trees to reach a threshold height ($\approx$4.5 m) sooner, beyond which trees become less susceptible (Lashomb and Steinhauer, 1974; Berisford, 1987; Meeker and Kulhavy, 1992). Where soil moisture conditions are favorable for rapid tree growth and nutrients are limiting, fertilization may increase pine growth as well as lower tip moth susceptibility. Fertilizing with nitrogen has resulted in slight reductions in tip moth attack, whereas applications of phosphorous resulted in significantly decreased infestation rates (Pritchett & Smith 1972). In response to fertilization, Ross & Berisford (1990) showed that Nantucket pine tip moth egg density, number of pupae per seedling, and pupal weight were directly related to host tree nutrient status, although larval survival was negatively correlated. In their study, nutrient and moisture conditions were controlled carefully in potted seedlings in a greenhouse before hosts were subjected to wild populations of adult tip moths. Berisford (1987) postulated that the increased general health of trees grown on better sites may lead to higher resin flow and increased resinosus of young tip moth larvae. These results indicated that moisture and nutrient conditions promoting vigorous plant growth throughout the stand produce a highly desirable host but supports only moderate tip moth infestations, presumably due to increased internal defense mechanisms, the ability to withstand successful attacks without noticeable damage, and greater associated protection. Highly productive sites also promote rapid host recovery from damage and reduced time spent in susceptible stages (Meeker and Kulhavy, 1992).

Fusiform Rust

Fusiform rust, *Cronartium quercuum* (Berk.) Miy. ex Shirai f. sp. *fusiforme*, is among the most destructive forest diseases in the South. Probably more documentation and scientific literature exists for fusiform rust than for any other disease of slash and loblolly pine. It is distributed from eastern Maryland to Florida and west to Texas and southern Arkansas. The incidence of the disease and hazard varies geographically, and in some high-hazard areas, it is impossible to economically manage slash and loblolly pine (Anderson et al., 1984). Longleaf pine is relatively resistant to fusiform rust and shortleaf pine may be considered immune for all practical purposes. However, as a result of planting and the reduction of fires, longleaf pine is being replaced in many areas by slash and loblolly pine. This has brought about an increase in the general abundance and the likelihood of epidemics and heavy losses from the disease in southern pine forests (Baxter, 1970). Today, efforts to reduce the harmful effects of fusiform rust are well established and wide ranging. Large industrial forest landowners generally establish the priorities of insect and disease threats by comparatively evaluating each insect or disease risk and assigning a corresponding economic value to these risks. This fungus impacts large industrial landowners' forests in many ways, ranging in severity from tree deformation to the mortality of nearly every tree in a forest stand (Myers and Coleman, 1985). In the South, this disease is a serious obstacle to the success of slash (in particular) and loblolly pine stands. And, in many areas, it is the main factor that adversely affects large tracts of plantation in the region (Baxter, 1970).

The life cycle of fusiform rust is complex but well documented. Often two years or longer are required for the rust's life cycle to go from the initial pine host, through the oak intermediate host back to the re-infection of pine (Myers and Coleman, 1985). The intermediate host of the rust occurs within the black oak group, especially water oak, (*Quercus nigra* L.), willow oak, (*Quercus phellos* L.), and laurel oak, (*Quercus laurifolia* Michx.). In early spring, orange aeciospores are released from pine and carried by the wind to the surfaces of young oak leaves where they germinate and cause local infections (Phelps and Czabator, 1978). Seven to ten days later, small pustules bearing orange urediospores develop on the undersides of the infected oak leaves, where, usually within a week, brown, hairlike telia form. Each telium consists of several hundred teliospores and may remain viable until early summer. Warm, humid weather promotes the germination of each teliospore which releases 3 to 4 sporidia. The sporidia may be caught by air currents and carried 1000 feet or more to infect susceptible pine tissue, completing the cycle. Infection of the pines takes place through the needles or succulent stem, usually from mid-April to mid-May (Baxter, 1970).

Dinus (1974) suggests that incidence varies in proportion to the intensity of forest management and is greatest where pine and oak distributions maximally coincide. In a study in northern Florida, Hollis and Schmidt (1977) showed that frequency of oak hosts, amount of susceptible pine shoot tissue, amounts of extractable soil phosphorous, and degree of internal soil drainage strongly influenced disease incidence. Climate was uniform and did not limit rust development. Oak abundance was the single most important factor and rust was most prevalent where susceptible pines and oaks grew best and in association with one another. The relative importance of site factors remains uncertain, especially on a regional scale. Among the seven oak species for which volume data were available, water oak distribution and abundance showed the greatest correspondence with percentage of pines infected. Water oak volumes generally increase from south to north, reaching a maximum at the corridor of greatest rust infection and decreasing beyond it. Also, both water oak volume and percentage of infection are high in southwest Georgia and low in southeast Georgia and southern Alabama. Volume of laurel oak tends to be correlated with that of water oak, and hence follows the pattern of infection on pines to some extent. However, high volumes of laurel oak extend into central and southern Florida, where infection on slash pine is low. Maximum volumes for this species occur further south than the region of greatest rust infection of loblolly pine.

On slash pine, incidence of fusiform rust was strongly related to abundance of water oak and weakly or moderately associated with abundance of other oaks. On loblolly pine, incidence was weakly positively correlated with abundance of only water and laurel oak. The relatively weak relationship of oak abundance for loblolly pine may be caused by natural resistance in some regions. Such resistance may have developed through natural selection in regions where water oak is abundant or through hybridization with shortleaf pine. Other oaks, not studied, may also be involved where they are prevalent and coincide with pine plantings (Squillace et al., 1978).

Fusiform rust is the most common disease affecting survival in loblolly pine plantations. How great an impact the disease has on future yields depends on site index, stand density, tree age, incidence of stem galls, age of the tree at initial infection, growth rate of surviving galled trees, and response of adjacent healthy trees to space provided by rust associated mortality or reduced growth rate (Shoulders and Nance, 1987). Fusiform rust has increased dramatically in response to plantation culture, which creates large areas of young, succulent tissue in the presence of abundant inoculum on oak and favorable environmental conditions. Although specific meteorological conditions are required for inoculum production and infection (e.g., moisture), climate is most often favorable in high-hazard areas (Anderson et al., 1984).

Fusiform rust is named for the spindle, or fusiform, shaped swellings it causes on the main stem and branches of pine trees. Fusiform rust first becomes noticeable as abnormal swellings form on the stems of 1-0 seedlings (Baxter, 1970). Fusiform rust infections can occur throughout the life of a stand, but the most serious ones occur during the first five years. Stem galls and branch galls near the stem are especially serious at this stage of development, since they frequently result in tree death. Later infections are less frequently lethal, but can cause significant degrade loss (Anderson et al., 1984). Mortality from trunk infection is highest in the seedling-to-pole stages. Older trees may live for a number of years, but they often break at the point where the canker is located. Although trunk infections are less serious on loblolly pine, even this species is often killed before pulpwood size is attained. If such trees live, extremely large cankers may form, which eventually cause extensive cull or degrade (Baxter, 1970). Gall formations on trees in older stands may result in deformities which weaken trees to the extent that economic management alternatives are often severely restricted in stands which are heavily infected (Myers and Coleman, 1985). In a study by Shoulders and Nance (1987), transitional probabilities for loblolly pine in unthinned plantations to develop fusiform rust stem infections and for survival of healthy and stem-galled loblolly pines were computed. Under similar levels of competition, stem-galled pines had markedly lower probabilities of survival than their uninfected neighbors. The trees age at infection and its competitive status within the stand affected probabilities for it to survive with a stem canker. Competition from neighbors was the main factor affecting probabilities for healthy trees to survive. Loblolly pine showed greater variability in its resistance to infection and in its tolerance to the disease than did slash pine in the same experimental plantings.

The pattern of fusiform rust infection within a plot could mask the true effect of the disease and the mortality attributed to fusiform rust for a number of reasons. First, infection does not necessarily guarantee damage. Second, the timing of infection and the size of the trees infected could influence the amount of mortality caused by the disease. For example, even if all stem galls were completely innocuous, the disease might appear to cause mortality if stem galls only developed on the smaller trees that have a high probability of death from competition. Alternatively, if the disease were innocuous and only infected the larger, dominant trees within a plot, mortality would be much lower among the infected trees, and a different impression of the mortality effects of the disease would result (Shoulders and Nance, 1987).

Since 1930, numbers of trees infected by fusiform rust have grown because of increasingly intensive silvicultural practices and increasing numbers of the alternative host oak. More than 138 million acres have pines with stem or branch galls, and 2½ million acres, or about 6 percent of slash and loblolly stands in the South, have more than 50 percent of their trees infected. Trees that are infected by age 5 often die. Later infections cause breakage during storms and reduce bole quality. As fusiform rust hazard increases, the need for effective controls become more urgent (Walkinshaw and Anderson, 1988). Numerous estimates exist for the timber loss in southern forests as a result of the mortality and degrade associated with fusiform rust. Myers and Coleman (1985) estimate that fusiform rust costs southern forest landowners $68 to $98 million per year. Powers and others (1974) conservatively estimated losses at $28 million annually. The cost to southern forest landowners is formidable and growing (Myers and Coleman, 1985).

Although disease incidence is widespread and localized areas of high incidence occur sporadically, rust is most prevalent in a corridor extending from southeastern Louisiana through southern and central Mississippi. Alabama, Georgia, and South Carolina (Phelps, 1973, Powers et al., 1974, Schmidt et al., 1974, Squillace, 1976). Louisiana showed a high incidence for slash and a low incidence for loblolly, while Florida showed the inverse (Myers and Coleman, 1985). Furthermore, incidence in the corridor decreases gradually to the northwest and southeast. Rust incidence in slash pine plantations was strongly correlated with abundance of water oak ($r = 0.68$) and moderately or weakly correlated with abundance of six other oak species ($r = 0.23$ to 0.48).

Incidence in loblolly pine was positively correlated only with water ($r = 0.42$) and laurel oak ($r = 0.48$) volumes. The lower correlation coefficients in loblolly may result from planting of rust-resistant stock in some regions. With oak volume held constant, incidence tended to be greatest in areas where April-May temperatures ranged from about 67° to 70° F; whereas warmer or cooler regions had less infection. When water and laurel oak volumes were considered along with April-May temperatures, multiple correlations with incidence were 0.77 for slash pine and 0.55 for loblolly pine. Although geographic origin of seed can greatly affect the amount of rust in plantations, it did not appear to be a major cause of the regional patterns of incidence. Further study is needed, but these findings suggest that forest managers should consider oak abundance (especially water oak) and average spring temperatures in assessing rust hazard (Squillace et al., 1978).

Hazard rating for fusiform rust is difficult. Site, species, cultural practices, and genetics of the seedlings are just a few of the factors to consider. Anderson et al. (1984) designed the following summary of the most current systems:

High Hazard	Twenty five percent or more of trees in current or adjacent stands infected in each of at least two years during five consecutive years. Trees frequently have multiple galls from a single year's infections. Oaks are abundant on or within 400 meters of the planting site. Telia are very numerous on oaks during April-June in most years.
Medium Hazard	Twenty five percent or more of trees in adjacent stands infected in one year during five consecutive years. Trees with multiple galls at more than one level are infrequent. Oaks are sparse within 400 meters, but may be abundant within 1,600 meters. Telia occur, but are not numerous in most years.
Low Hazard	Less than 25% of trees in adjacent stands infected in any one year during five consecutive years. Trees with multiple galls are rare. Oaks are rarely found within 1,600 meters.

Some loblolly and slash pine families are genetically resistant to fusiform rust. For years, managers and researchers rated resistance based solely on whether trees in the field were infected. They have known for some time, however, that some infections are more serious than others, and that certain distinct shapes and sizes of galls are indicators of certain kinds of resistance. In thinning infected stands, foresters have long recognized that branch galls are generally less serious than stem galls, and that branch galls more than 12 inches (30 centimeters) from the main stem are not likely to spread to the stem. Researchers have also observed that certain types of galls are indicators of a family's probable performance in areas of high rust hazard. If the numbers of families that remain free of rust were ample, interest in other forms of resistance would be slight. Unfortunately, numbers of resistant families are severely limited, and all markers of resistance are needed. Judicious selection of species for planting, alterations in site preparation, salvage removal of infected stems in the field, and chemical control in nurseries can help to reduce losses. The most promising way to minimize losses while growing the most desirable species is by planting resistant stock in areas of high rust hazard (Walkinshaw and Anderson, 1988).

Fusiform rust can cause increased mortality, and the presence of stem cankers reduces the value of the infected trees for lumber production (Busby and Haines, 1988). Large industrial forest managers' management philosophy is equally as difficult as the researchers' approach toward reducing the effects fusiform rust has on southern forests. Unfortunately, many things the managing forester does to accelerate early plantation growth may also promote the infection and impact of fusiform rust on the same stand (Hollis, 1976). Genetics, thinning, fertilization, and other measures employed to enhance growth rate are sometimes reported to singly or collectively worsen the stand's problem. The introduction of rust-free phenotypes into tree improvement programs has made progress in reducing the infection rates in young stands. The fungicide Bayleton™ is a powerful tool for use in reducing nursery bed infection rates (Myers and Coleman, 1985). Finding a solution is very important if forest managers are to evaluate alternative management strategies to cope with fusiform rust infections (Busby and Haines, 1988).

Control that depends on prevention of infection of nursery stock through weekly spraying with Bordeaux mixtures should begin from the time the burlap is lifted until mid-June. It is possible to increase the efficiency of such treatments by timing their application to days when the infection hazard is high. Since the aeciospores produced on pine and the urediniospores produced on oak cannot infect hard mature oak leaves, intensity of infection on oaks depends on a race in development between the pathogen and oak foliage. Warm weather in late winter is favorable for buildup of the uredinial stage on oaks. With this in mind, it is to be expected that spraying to control the disease in the nursery is most effective if treatments are (*a*) deferred until fruiting stages of the rust first appear on the oak leaves in the vicinity of the nursery, or (*b*) deferred when daily average temperatures are not above 56° Fahrenheit, or (*c*) timed so as to precede periods of general precipitation or of high humidity. Spraying should be continued until June 1, with at least one application each week. A 4-4-50 Bordeaux mixture (with a good sticker and spreader added) or a liquid lime-sulfur 1-50 spray has been recommended (Putnam and Bull, 1940).

Control measures that would involve the eradication of either the oaks or all cankers on pine are usually not practical. Many stands can survive with some disease without sustaining losses that would justify direct control efforts. Culling of infected stock is one preventative measure in general use. And whenever possible, slash and loblolly pine should be planted at least on sites where rust incidence is low. The local hazard can be judged by a survey of fusiform cankers on young pines within a mile of the planting site. If nine or ten percent of the saplings of pole-sized trees are infected, the hazard is considered to be high. If sites of high hazard cannot be avoided, loblolly should be favored over slash wherever the former grows satisfactorily. It has been demonstrated that rust infection is lower in slash pine sown late than in beds of the same species planted earlier. Seeding should be as late as possible without endangering the production of plantable stock (Baxter, 1970).

Wise site selection may serve to reduce disease incidence in the field. Possible planting of longleaf or shortleaf pine on the site should also be considered. There is increasing evidence that rust damage can be minimized if dense stands are established and maintained. On sites of high hazard, plantation spacing of four by four feet or four by five feet is preferable to six by six feet. It is more satisfactory to leave some of the infected trees than to thin too heavily. To be effective, thinnings should first remove stem-cankered trees and those with branch cankers within fifteen inches of the bole. If this practice thins the stand too much, it is advisable to leave trees with branch cankers farthest removed from the stem. In commercial thinnings, cankered trees are marked for cutting because such pine is subject to early breakage. Removal of infected trees to reduce spread of the fungus is of doubtful value.

The widespread use of pruning has practical limitations since at least two or three prunings may be necessary to prevent most trunk cankers. However, a single pruning, if timed to follow the occasional year of heavy infection, may prove helpful. Fire, at present, cannot be recommended as a canker control measure. The planting of seedling stock from different geographic sources and the vegetative propagation and breeding of resistant strains are additional possibilities for securing control. Trees that break dormancy earliest in the spring, it seems, are the most susceptible to infection. Furthermore, it is apparent that most damage is traceable to the occasional years of heavy infection. Special care is advocated in rouging nursery stock in such years and timing later pruning operations in the plantation (Baxter, 1970).

Here is a summary of some important points in managing the damage caused by fusiform rust:

1. Avoid movement of rust-infected stock from the nursery (all sites).

   Produce disease-free seedlings in nurseries by careful application of Bayleton. Cull seedlings with galls prior to outplanting. The presence of seedlings with galls in nursery beds will indicate the likelihood of additional seedlings with latent rust infections.

2. Use resistant seeds or seedlings, if available (high, medium hazard sites).

   Avoid planting rust-susceptible pines on high-hazard sites. These sites should be regenerated with seedlings from:

   - rust-resistant slash and loblolly pine seed orchards and seed production areas, or
   - geographic areas of resistance; e.g., Livingston Parish, La., east Texas (use resistant local sources, when possible), or
   - resistant species; e.g., longleaf, shortleaf, and sand pine, where appropriate.

3. Reduce oak population when practical and not in conflict with other management practices (all sites). Use management techniques (e.g., hot summer burns prior to planting or herbicides) which reduce the amount of susceptible oaks, especially water and willow oak, in or adjacent to pine plantings and nurseries. Indiscriminate eradication of oak trees is not recommended, and careful attention should be given to the value of oaks for wildlife food and habitat, aesthetics, and land values.

4. Alter fertilization schedule (High hazard areas).

   If fertilization is planned, and more than 25% of the trees in the stand or adjacent stands is rust infected, delay application until age eight to ten. Fertilizer may predispose pines to infection by promoting more succulent tissue. Losses which result from infection after trees are eight to ten years old are much reduced.

5. Use seed tree or shelterwood regeneration (High hazard areas).

   When heavily-infected plantations are harvested and an adequate number of residual, rust-free trees are available, consider using a seed tree or shelterwood system to regenerate the stand. The seed from rust-free trees will confer some genetic resistance to the future stand, and these regeneration methods may provide an unfavorable microclimate for infection. This practice is most appropriate for small woodlots when rust-resistant seed is not available and when intermediate harvests are desirable.

6. Consider planting density (High hazard areas).

   Decisions on planting density are best made using growth and yield equations which include fusiform rust as one of the components. Use of these equations is described by Kuhlman, Froelich, and Blakeslee (1984). Increasing density to compensate for rust mortality may result in an increase in the number of infected trees and a significant increase in the quantity of inoculum in the early years. If mortality does not occur, the stand will be overstocked, which will result in rapid pruning of branches and a reduction in rust, but the resulting stress may provoke other pest problems; e.g., pitch canker.

7. Heavily-infected stands--regenerate or manage to rotation (All sites).

   Each planting should be evaluated at age three to five to determine whether enough rust-free trees are present to maintain the stand to rotation age. As suggested earlier, growth and yield models that include fusiform rust as a component are available for unthinned slash pine plantations and will help to make this determination. Schmidt and Klapproth (1982) provided a model for estimating rust incidence hazard and losses for pine plantations. Redmond, Uhler, and Anderson (1983) have developed an economic computer model that compares the alternatives of stand liquidation or continued management at age five to eight.

8. Delay prescribed burning (High, medium hazard areas).

   In merchantible stands, prescribed burning should occur after stem-cankered trees are removed in thinnings. Since rust galls are easily ignited and tree death or excessive charring may result, prescribed burning in young infected stands should be avoided until the trees are at least nine to ten years old (Anderson et al., 1984).

By using common sense and the information presented here, some control over the presence of the disease within a stand and the damage done to the pine component may be achieved. Through preventative management starting from the seed stock throughout the life of the stand, a healthy, relatively rust-free forest may be achieved.

Annosus Root Rot

Another of the most important and studied of forest diseases is annosus root rot, *Heterobasidion annosum* (syn. *Fomes annosus* (Fries) Karst.) (Aphyllophorales, Polyporaceae). It causes damage in managed and unmanaged forests after thinning and harvesting in most regions where coniferous forests grow. Its range spans much of the United States, including Alaska. It can also be found in British Columbia and southern Ontario, though it has not been reported in the boreal forests of central or eastern Canada. *H. annosum* has been reported as colonizing and producing basidiocarps on approximately 200 species of plants, including some that are nonwoody. The fungus is only an important pathogen on gymnosperms, but angiosperms may also be lethally attacked if they grow in the presence of conifer roots colonized by the pathogen. Damage to forest productivity has been most severe in the southeastern United States, where intensive forestry has been practiced the longest. Surveys indicate the presence of the pathogen in a majority of the loblolly and slash pine plantations in this area. Fortunately, only a minority of these plantations occur on sites conducive to severe damage. Following thinning in some high hazard areas, mortality rates of slash pine in excess of 40% due to root rot have been reported, and living infected trees have sustained losses of 20-32% in diameter growth and 40% in height growth during the first 6 years after the operation. In the West where damage by *H. annosum* alone is less severe, the fungus often works with other root pathogens which collectively cause tree mortality or growth loss. The ability of *H. annosum* to exist either as a parasite in living trees or as a saprophyte in stumps gives the fungus the ability to remain in an active condition for decades, ready to attack a new crop of trees (Anonymous 1961).

H. annosum enters a stand by means of basidiospores, conidia, or mycelium. The most common method is via airborne basidiospores that germinate on freshly-cut stumps or other wounds that expose sapwood. Basidiospores and conidia may also percolate with rain water into coarse soil and there initiate infection on wounded roots of vigorous trees or on unwounded roots of stressed trees. This allows the fungus to enter stands where no cutting has been done. Conidia may survive up to 10 months in some soils, and few conidia are needed to infect unwounded stump roots. Conidia are not airborne, but it has been suggested that they may be dispersed by water and insects. Their role in the epidemiology of the fungus is unknown. Germinating *H. annosum* basidiospores enjoy little competition in the freshly-cut sapwood of conifers which acts as a selective medium that allows the growth of few other fungi. However, this advantage disappears after a few weeks or even less in warm weather, when various saprophytic organisms begin to grow in and compete for the same substrate. But this time allows the mycelium of *H.*

annosum to colonize the stump and to grow out into its roots. It is well established that root grafts are common in the monoculture of planted pine stands, and since the fungus cannot grow free in the soil for more than a few millimeters, it uses these root contacts or grafts for transmission to adjacent, healthy trees. Once transmitted, the fungus may then weaken or kill the new healthy tree by decaying the tissue within the roots and root collar (Boyce 1961). Parasitic growth through living roots is slow because of host resistance, but growth in dying or recently dead roots is relatively rapid. Growth of the fungus in roots has been measured as ranging from 1.5-6.0 feet per year, depending on the strain of pathogen, host material, temperature, and soil conditions (Sinclair, et al., 1987; Mason, 1967). After about one or two years, infected trees and stumps may begin to produce basidiocarps, thus contributing to the buildup of the disease. The spores produced in these basidiocarps may travel as far as 200 miles to infect other trees (Matthews 1961).

Plantations heavily infected with *H. annosum* may often be recognized by the presence of infection centers surrounded by dead and dying trees (Mason, 1967). However, except for the decay, these symptoms of annosus root rot are not diagnostic since other root pathogens may cause similar symptoms (Sinclair, et al., 1987). In any case, the openings created are often recognized as large sunny spots and may be vegetated by various weeds and grasses which make them visible for some distance. Living, infected trees surrounding the opening may have thin, yellowed crowns, often with "needles feathered into foxtails on the limbs." In more advanced stages of infection, defoliation of the lower crown or even the entire tree may take place (Matthews 1961). Upon closer observation of the area, characteristic fruiting bodies, or basidiocarps, of the fungus may be found. Fruiting bodies most often occur where the base of a stump, or dead or dying tree, may be covered by litter or vegetation. Here, the high humidity of 92% or greater that is required for growth, is maintained for long periods.

Basidiocarps vary in size and shape, from tiny white plaques consisting of little more than a tube layer to bracketlike conks up to 25 cm across. Some are perennial, but most live less than one year. They may form on stumps as soon as 18 months after cutting and then develop more or less annually until the substrate is exhausted (Sinclair et al., 1987). The lower surface of a young basidiocarp is white, and is covered with visible pores in which the basidiospores are produced. With age, this white coloring generally turns more tan or brown. When a growing basidiocarp encounters an obstruction, such as a small root, stick, or conifer needle, it grows around it and incorporates it into its structure, rather than push it aside. Another useful aid in identification are the small pustules of mycelium which do not grow into fully formed fruiting bodies (Anonymous, 1961). These pustules, as well as the fully formed basidiocarps, can generally be found on stump or root surfaces just beneath the litter layer or below-ground in animal burrows or cavities. Resin flow from the butt of the tree and resin filled roots may also be associated with the infection. Excess resin oozes from the roots and mixes with the soil, forming encrustations on the root surface. When young trees are killed, thin white mycelial fans, not noticeably veined, can be found between the bark and wood. As decay begins, elliptic to elongate white pockets, often containing single black specks, form by the dissolution of host tissues in the cambial zone. The wood gradually turns weak, soft, and stringy but not brittle, and may also have tiny elongate pockets that sometimes contain black specks. This decay is called a white pocket rot, a white stringy rot, or sometimes a laminated rot, depending on the host infected.

All hosts may sustain root death or decay from *H. annosum*. In young trees, especially among pines, foliage may turn brown and drop rapidly with no prior indication of distress. This leaf drop indicates the rapid killing of the bark and cambium at the root collar. Older trees may decline during one or more years before death, but these trees often have short, sometimes chlorotic, needles in tufts at twig tips. In general, pines can tolerate the loss of half their roots before growth suppression becomes noticeable. If *H. annosum* is present in a given stand, many more trees are infected than can be detected on the basis of symptoms and signs (Sinclair, et al., 1987). Depending on locality, symptoms of the disease may not first appear until six to ten years after the initial infection (Low, 1958). Root rot, windthrow due to rotted roots, butt rot, suppressed growth, and tree mortality are all potential symptoms of the fungus. Though the heartwood in older trees is generally able to resist decay, the trees may suffer loss in diameter growth (Mason 1967; Sinclair 1987).

Pine stumps on low hazard sites may become infected by *H. annosum* as frequently as stumps on high hazard sites. However, on the high hazard sites the disease spreads more readily into the residual stand (Kuhlman, 1973). High hazard sites are deep, alkaline, well drained sands and low hazard sites are sands with higher water tables or heavy clay. Morris and Frazier (1966) demonstrated that sand was the most significant soil factor, though other significant soil parameters were pore size, field capacity, clay, and organic matter. Organic matter, potassium, and magnesium were shown to be significantly greater on non-infected sites than infected sites (Mason, 1967). Sand and large pores were found to be directly related to infection, with small pores, field capacity, clay, and organic matter inversely related to infection (Alexander and Skelly, 1973). Phillips and Burdekin (1982) found a relationship between soil pH and infection. They discovered that trees growing in soils with a pH above 6 had high mortality, whereas mortality was less significant soils with a lower pH. The hazard of stump infection also varies with season and climate, based on basidiospore dispersal. Spore dispersal and stump infection occur all year in the Pacific Northwest, but mainly in spring and autumn in the Northeast and during autumn and winter in the South. Landscape and ornamental plantings are typically not affected by the fungus, apparently because thinning and harvesting activities do not occur and environmental conditions are not conducive to infection and growth of the pathogen (Sinclair et al., 1987).

At present, all methods of management of *H. annosum* are aimed at prevention. The most widely recommended method is the treatment of stump surfaces with such chemicals as borax (sodium tetraborate), urea, or creosote (Mason, 1967). These treatments must be applied immediately to freshly-cut stump surfaces following cutting to prevent spore germination and may be effective for up to six months (Driver 1963). Many investigators have studied the competition between *H. annosum* and other organisms inhabiting stumps, litter, and the soil. Among these organisms, *Trichoderma viride* Pers. ex Fries and *Peniophora gigantea* (Fries) Masse seem most promising in controlling *H. annosum* (Curl and Arnold 1964). Of these two, *P. gigantea* is believed to be of greatest value. Hodges (1964) observed it growing over *H. annosum* and replacing it in stump roots. But it is most effective when stump surfaces are colonized prior to infection by *H. annosum*. Since *P. gigantea* can live only as a saprophyte, it poses no threat to living trees. Protection against stump infection by *H. annosum* might be achieved by cutting and inoculating scattered trees within the stand with *P. gigantea* several months prior to thinning. These would produce basidiocarps and inoculate stumps after thinning (Boyce, 1966). Studies suggest increased stump infection if cutting is preceded by about 14 to 22 days of warm, humid weather. However, infection tends to decrease if there is rainfall within about 7 days prior to cutting, possibly because the rain cleans the atmosphere of spores (Yde-Anderson, 1962). Also of importance is the fact that basidiospore dispersal is inhibited during the winter in the North and during the summer in the South. In parts of the South, stump surface temperatures in the summer rise high enough to prevent colonization by *H. annosum* (Sinclair et al., 1987). Most conifers tend to become relatively resistant at 15 to 25 years of age, depending on the site. Chances for infection will likely be greater following harvest of the original crop due to the presence of infected stumps. Other means of prevention include planting less susceptible species on high hazard sites, maintaining wide spacing to prevent root contact, using more care in planting, and reducing the frequency of thinning (Matthews, 1961).

METHODS

Geographic Information System (GIS)

To aid in the visualization of field data collected and determination of pest occurences and problems within the LAAP study area, a GIS was constructed. The steps involved in the creation of the GIS are described below.

Global Positioning Satellite (GPS) data were taken at road intersections and at SPB traps, NPTM lines, and BA study plots using the Trimble Pathfinder TDC1 reciever. The data were downloaded onto a PC-based computer running PFPRO (by Trimble) software. Using PFPRO, the data were differentially corrected with data from the Arthur Temple College of Forestry (ATCOF) base station unit. Corrected receiver data from the TDC1 are generally accurate to within a meter according to the unit's specifications. The corrected data were then exported into a point format (*.pts) usable by the ATCOF's current ARC software and sent via file transfer protocol (ftp) to the RISC/6000 computers where the ARC software was located. Once on the RISC/6000 work station, the data were converted to a point coverage (*.cov) using the UTM - Zone 15 coordinate system in ARC.

To provide a base image onto which other coverages and images may be layered, a raster image was cut out and saved from one of the Sure!Maps® CD-ROMs of Texas. Because Sure!Maps® was located on the same PC-based computer as PFPRO, the saved image had to be transported to the RISC/6000 computers using ftp. Using Command Tools in ARCTOOLS, the image was registered and rectified to the GPS point coverage created earlier. The newly georeferenced image was then saved as the base image in ARCVIEW.

Pages inclusive of the study area from the Harrison County Soil Survey were scanned into a PC-based computer. The scanned images were transported over to the RISC/6000 platform for use in the creation of the soils coverage. Using Command Tools in ARCTOOLS, the scanned images were registered and rectified to the base image using the GPS points coverage. Using Edit Tools in ARCTOOLS, the registered soil survey images were brought up as background images and a new vector coverage for soils was created by digitizing lines over the soil lines on the scanned images. The digitized lines of the soils coverage were then converted to polygons for use in ARCVIEW. In ARCVEIW, data for the particular soil polygons including soil type, available water, pH, drainage, and later annosus root rot hazard rating were added to the soils attribute table.

In ARCVIEW, the southern pine beetle traps, NPTM lines, and BA plots were all displayed as points from the GPS points coverage created earlier. The respective points were color coded for theme differentiation. Field data collected from the various study plots (SPB, NPTM, BA Plots) were added to the respective attribute tables. The data within the soils attribute table was used to determine a risk for annosus root rot. Once a risk was assigned within the table, the soils were grouped according to their annosus root rot hazard rating. The grouped soils were then converted into a shapefile for each hazard class.

Still photographs taken of the Lindgren funnel traps, NPTM sample lines, and basal area plots were scanned into the PC-based computer and transported over to the RISC/6000 computers. The scanned images were then hot-linked to the respective points on the GIS to provide a visual record of the study area at the time of data collection.

Aerial Videography

The effectiveness of aerial videography for use in the hazard rating of pine stands for the southern pine beetle was evaluated through comparison with ground-based hazard rating using the SPB hazard rating system for Texas, proposed by Mason et al. (1981). Ten permanent plots, each with sub-plots one-tenth acre in size, were selected on the ground for stands with basal areas, tree height, tree diameters, and stand composition varying from a dense young pine stand to a 30 BA mature pine stand. Aerial videography was taken in July of 1997 at an altitude of about 1000 feet above ground level (AGL) (Figs. 5-19). Videography taken earlier that year at about 2000 feet AGL was not adequate for bark beetle hazard rating in this particular study due to decreased resolution and excessive tilt, pitch, and roll which caused numerous "holidays" (gaps in coverage) and scale problems.

Frames from the second flight of the color aerial videography selected to display the ten permanent plots were copied for use in the GIS. These frames which displayed the plots were mosaicked together to allow a larger area to be seen. This was completed by connecting a SuperVHS VCR to a Macintosh Power PC 9500 with video editing software via coaxial cable. As the video from the second flight was advanced on the VCR, the corresponding image on the computer could be frozen and saved as an image (*.tif) file. Many frames were used to get full coverage of the plot areas. The images were then opened up on the same computer in Adobe Photoshop. Images which would be used together to make up one plot were opened together and "rubber sheeted" together, matching roads and other distinctive objects. These mosaics were then saved as a single file and transported to the RISC/6000 computers. Using Edit Tools in ARCTOOLS and the GPS points coverage, the images were registered and rectified. The newly georeferenced images were then placed into ARCVIEW.

Canopy coloration was used to differentiate pine and basal area (Figs. 6-16). Heights were estimated from the videography using the proportional shadow method (Paine 1981). Landform for each area was classified from the GIS Sure!Maps® base image. A ground check was used to determine interpretation accuracy within each area. Field work included measurement of basal area, tree height, tree species, landform, and the apparent occurrence of pest organisms.

Southern Pine Beetle

Six Lindgren® funnel traps each baited with alpha-pinene, frontalin, ipsenol, ipsdienol, and Klean-Strip® steam distilled turpentine were used to monitor numbers of the southern pine beetle and associated insects. The traps were placed throughout the military installation in pine stands less than 80 basal area, so that the traps would be at least thirty feet away from any pine tree (as directed for use of Lindgren funnel traps). The traps were set out on March 7, 1997, and catches were collected weekly from then through July 11, 1997. The insects were separated and counted by species. Anticipated trap catches included the southern pine beetle (SPB), the Ips engraver beetles (*Ips avulsus, I. grandicollis,* and *I. calligraphus*), the black turpentine beetle, (*Dendroctonus terebrans*), the southern pine sawyer, (*Monochamus tittilator*), regeneration weevils, (*Hylobius sp.* and *Pachylobius sp.*), and bark beetle predators (*Thanasimus dubius* and *Temnochila virescens*). Maximum trap catch of SPB was expected to be in early spring and tapering off into the hotter parts of the summer. Global Positioning System (GPS) points were taken at each of the sampling sites. Pheromones and the Lindgren funnel traps were purchased from Phero-Tech, Inc., Delta, British Columbia, Canada (Dr. Ronald F. Billings, personal comm.).

Nantucket Pine Tip Moth

Fifteen transect lines each 120 feet in length were used to determine the infestation rate and hazard of Nantucket pine tip moth. The location of the lines was determined by the availability of areas of pine regeneration sufficient in size to support the length of the sampling line. The pine stands sampled consist of natural regeneration growing under power lines and on roadsides. On each line, twenty trees approximately six feet apart were counted. Tree height, diameter of the crown, diameter of the root collar, and the number of tips were measured for each tree. Each sample tree was divided into four sections in which tips were counted, including: 1) the terminal bud, 2) the top whorl minus the terminal bud, 3) the top one-half of the crown minus the top whorl and the terminal bud, and 4) the bottom half of the crown. Tips were counted as total tips and infested tips for each section.

On each line, a bucket auger was used to dig a hole to clay. The depth of the A horizon and the distance to clay were then measured. The soil texture at two feet was obtained from the Harrison County Soil Survey. Hazard rating models by White et al. (1984) and Wilson (1984) were compared to determine which model would best match the observed infestations. A GPS unit was used to determine the location of the sample line. The GPS points were taken at the first tree of each line and a compass was used to measure the approximate direction of the line. Each sample line was placed onto the GIS for future needs.

Fusiform Rust

Fusiform rust incidence was sampled on the ten one-tenth acre plots used for the aerial videography sampling. Trees within the plots were divided into healthy, diseased, or dead from fusiform rust. Also, location of the canker on the tree was noted. A tree was considered diseased if it had a stem or branch canker.

Annosus Root Rot

The study area was hazard-rated for annosus root rot using soil characteristics and site index obtained from the Soil Survey for Harrison County. High hazard sites are typically described as having: 1) depth to clay = 12 inches, 2) pH > 6, often land once used for farming, 3) thick litter layer. Low hazard sites have: 1) a high water table, 2) high clay content within top twelve inches of soil, 3) poor water drainage, 4) and on both wet and dry sites, poor quality sites can be considered low hazard (Froelich et al., 1977). In each of the plots, trees were examined for sporophores around the base of the tree. Also, one section of soil, each one-cubic-foot in size, per plot was examined for evidence of infection (Alexander and

Anderson, 1985). The results from these field measurements were used to determine the actual occurrence of the disease in the forest.

RESULTS

Southern Pine Beetle

The hazard for southern pine beetle for the study was moderate, with two areas rated as high hazard for infestation using the Mason et al. (1981) model (Table 1). The agreement between the two systems indicates that these methods are interchangeable. However, the trap catches indicated a low risk for SPB (Fig. 2, Table 2).

Table 1. Hazard for southern pine beetle infestation in pine stands at the Longhorn Army Ammunition Plant using the Mason et al. (1981) model for prediction.

Stand Number	Mason
1	moderate
2	moderate
3	moderate
4	high
5	moderate
6	moderate
7	very low
8	moderate
9	moderate
10	high

Table 2. Actual infestation as measured from pheromone trap catches from Longhorn Army Ammunition Plant throughout the trapping period.

Trap Number	Mean Number SPB/Trap/Day	Mean Percent SPB	Trend Prediction
1	28	22	declining/low
2	9	18	declining/low
3	11	36	static/moderate
4	15	15	declining/low
5	20	20	declining/low
6	12	28	declining/low

Figure 2. Locations of the Lindgren funnel traps used to sample Southern pine beetle and related insects at Longhorn Army Ammunition Plant.

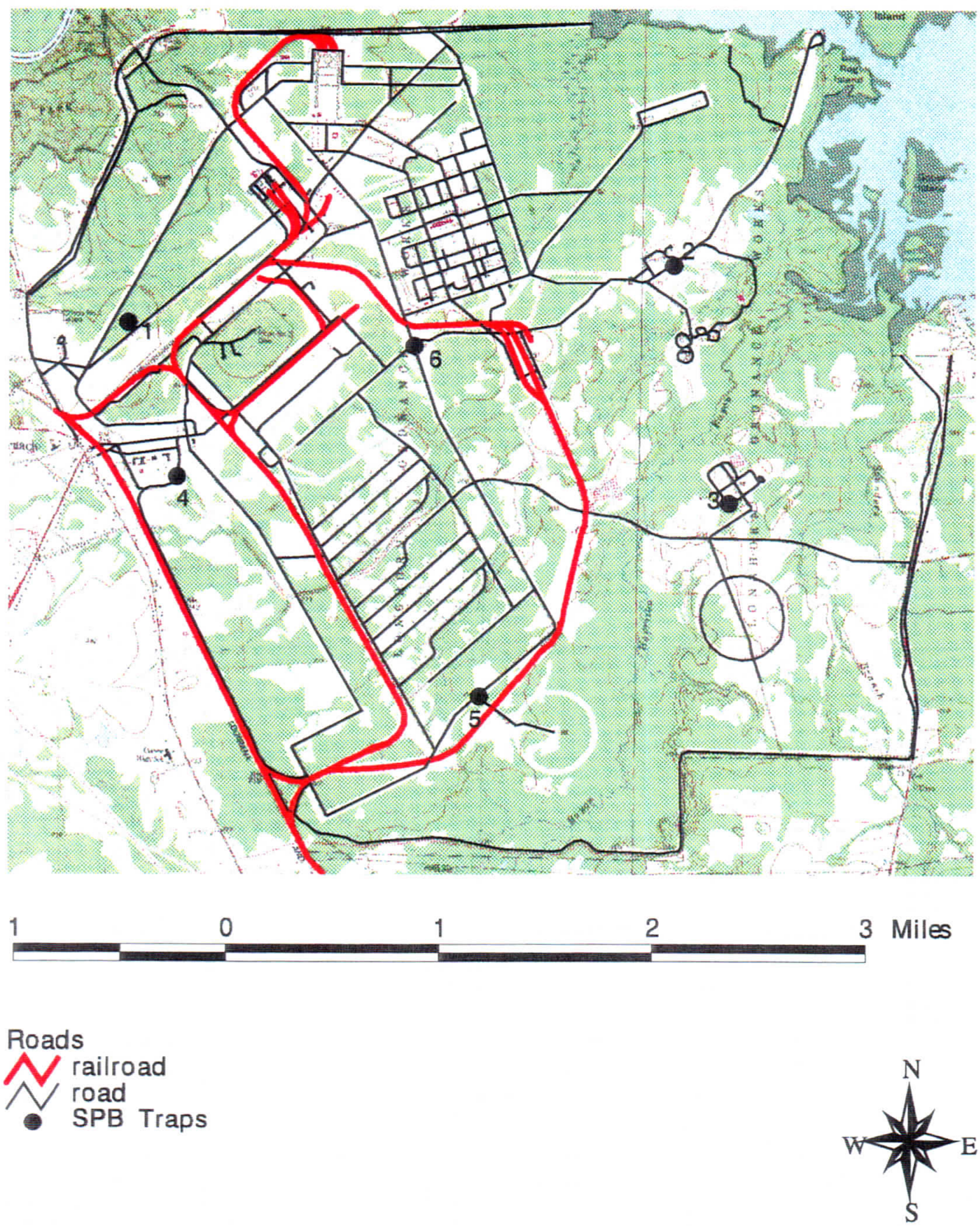


Table 3. Trap one catch of total insects, important wood-boring insects and their insect predators by date.

Date	Total Insects	*Dendroctonus frontalis*	*Ips avulsus*	*Ips grandicollis*	*Ips calligraphus*	*Dendroctonus terebrans*	*Platypus flavicornis*	*Xyleborus sp.*	Reproduction Weevils	*Thanasimus dubius*	*Temnochila virescens*
3/14/97	698	223	0	0	0	0	14	6	5	407	12
3/21/97	313	51	0	0	0	0	0	7	6	223	12
3/28/97	830	36	0	16	1	0	3	13	4	655	80
4/4/97	510	40	0	31	0	0	1	19	1	326	82
4/18/97	76	9	0	10	0	0	0	1	0	36	8
4/25/97	231	30	0	28	0	0	0	14	3	63	35
5/2/97	116	10	8	38	2	0	1	3	1	13	6
5/9/97	186	22	4	34	0	2	11	13	14	34	15
5/16/97	106	4	0	24	1	0	18	13	1	16	3
6/6/97	208	0	4	133	0	0	14	3	0	9	8
6/27/97	137	10	0	66	0	1	1	3	0	6	3
7/4/97	77	4	0	18	7	0	0	0	1	8	6
7/11/97	87	5	0	25	9	0	0	0	0	2	7
Total	3575	444	16	423	20	3	63	95	36	1798	277

Table 4. Trap two catch of total insects, important wood-boring insects and their insect predators by date.

Date	Total Insects	*Dendroctonus frontalis*	*Ips avulsus*	*Ips grandicollis*	*Ips calligraphus*	*Dendroctonus terebrans*	*Platypus flavicornis*	*Xyleborus sp.*	Reproduction Weevils	*Thanasimus dubius*	*Temnochila virescens*
3/14/97	330	61	0	7	0	0	0	46	11	172	7
3/21/97	140	7	0	4	1	0	1	2	3	105	5
3/28/97	264	10	0	4	0	1	1	13	11	165	46
4/4/97	190	6	0	8	0	0	0	7	7	141	11
4/18/97	54	3	0	4	0	0	0	2	1	32	4
4/25/97	171	8	0	59	2	0	0	16	4	32	24
5/2/97	185	7	4	91	1	0	0	15	3	31	12
5/9/97	195	3	3	67	1	0	2	30	7	25	15
5/16/97	155	1	3	90	0	0	1	14	3	14	6
6/6/97	493	0	4	423	0	0	2	0	0	4	24
6/27/97	161	0	0	114	1	0	0	3	1	0	11
7/4/97	103	0	0	56	2	0	1	0	0	1	13
7/11/97	127	0	0	55	3	0	0	2	1	2	14
Total	2568	106	14	982	11	1	8	150	52	724	192

Table 5. Trap three catch of total insects, important wood-boring insects and their insect predators by date.

Date	Total Insects	*Dendroctonus frontalis*	*Ips avulsus*	*Ips grandicollis*	*Ips calligraphus*	*Dendroctonus terebrans*	*Platypus flavicornis*	*Xyleborus sp.*	Reproduction Weevils	*Thanasimus dubius*	*Temnochila virescens*
3/14/97	248	54	0	5	0	1	2	87	2	64	3
3/21/97	135	25	0	27	0	0	2	17	0	32	1
3/28/97	184	16	0	39	2	0	0	28	3	47	20
4/4/97	209	10	0	48	0	0	0	7	3	85	34
4/18/97	47	1	0	11	1	0	0	0	0	12	0
4/25/97	170	13	0	63	2	0	0	26	4	11	9
5/2/97	234	5	7	157	4	0	0	24	2	5	1
5/9/97	101	3	1	35	0	0	0	18	1	3	2
5/16/97	130	0	5	73	1	0	0	20	2	4	4
6/6/97	578	1	3	505	1	0	0	3	2	2	19
6/27/97	248	0	1	175	2	0	1	1	0	1	11
7/4/97	289	1	1	208	6	0	2	3	0	1	9
7/11/97	246	0	0	162	3	0	0	3	0	0	0
Total	2819	129	18	1508	22	1	7	237	19	267	113

Table 6. Trap four catch of total insects, important wood-boring insects and their insect predators by date.

Date	Total Insects	*Dendroctonus frontalis*	*Ips avulsus*	*Ips grandicollis*	*Ips calligraphus*	*Dendroctonus terebrans*	*Platypus flavicornis*	*Xyleborus sp.*	Reproduction Weevils	*Thanasimus dubius*	*Temnochila virescens*
3/14/97	412	81	0	3	0	4	3	28	14	249	5
3/21/97	233	31	0	3	0	0	1	10	5	162	3
3/28/97	451	18	0	7	1	0	0	8	18	368	15
4/4/97	324	12	0	14	0	0	0	5	8	257	8
4/18/97	141	8	0	13	2	0	0	1	1	82	3
4/25/97	158	13	0	30	0	0	0	27	6	39	11
5/2/97	147	5	15	38	0	0	1	20	2	19	0
5/9/97	190	10	4	55	0	1	1	29	7	22	6
5/16/97	107	5	1	29	0	0	3	9	1	28	4
6/6/97	426	3	0	345	0	0	5	2	2	14	10
6/27/97	78	0	0	52	0	0	0	0	0	2	4
7/4/97	76	0	3	40	2	0	0	1	0	0	7
7/11/97	64	0	0	37	2	0	1	0	1	1	1
Total	2807	186	23	666	7	5	15	140	65	1243	77

Table 7. Trap five catch of total insects, important wood-boring insects and their insect predators by date.

Date	Total Insects	*Dendroctonus frontalis*	*Ips avulsus*	*Ips grandicollis*	*Ips calligraphus*	*Dendroctonus terebrans*	*Platypus flavicornis*	*Xyleborus sp.*	Reproduction Weevils	*Thanasimus dubius*	*Temnochila virescens*
3/14/97	457	126	0	3	0	5	4	37	10	260	11
3/21/97	268	38	0	2	3	0	2	3	18	189	6
3/28/97	507	46	0	12	2	1	1	12	18	358	44
4/4/97	387	22	0	38	1	0	1	19	11	225	53
4/18/97	97	7	0	18	1	0	0	6	5	31	5
4/25/97	258	31	0	37	1	0	0	45	20	59	26
5/2/97	233	16	16	80	0	0	4	50	4	18	8
5/9/97	287	13	19	66	1	1	29	74	10	16	12
5/16/97	130	5	6	55	0	1	5	21	1	11	6
6/6/97	361	3	7	249	0	0	19	8	3	3	13
6/27/97	188	1	2	86	1	0	2	2	4	3	24
7/4/97	234	0	0	159	1	0	5	1	2	0	9
7/11/97	171	1	0	72	1	0	0	5	0	0	16
Total	3578	309	50	877	12	8	72	283	106	1173	233

Table 8. Trap six catch of total insects, important wood-boring insects and their insect predators by date.

Date	Total Insects	*Dendroctonus frontalis*	*Ips avulsus*	*Ips grandicollis*	*Ips calligraphus*	*Dendroctonus terebrans*	*Platypus flavicornis*	*Xyleborus sp.*	Reproduction Weevils	*Thanasimus dubius*	*Temnochila virescens*
3/14/97	225	76	0	2	0	4	3	30	3	98	7
3/21/97	106	15	0	1	0	1	0	0	6	79	0
3/28/97	206	16	0	2	1	1	0	12	18	134	11
4/4/97	160	8	0	27	0	0	0	5	15	80	9
4/18/97	54	12	0	6	1	0	0	1	0	19	1
4/25/97	221	21	0	38	0	1	0	85	8	24	1
5/2/97	296	17	5	54	1	0	0	149	0	15	2
5/9/97	303	4	13	58	0	0	7	123	9	20	7
5/16/97	185	8	5	65	4	0	3	38	1	24	3
6/6/97	534	6	3	441	1	0	9	11	1	5	1
6/27/97	174	16	1	89	3	0	3	1	0	0	9
7/4/97	139	2	0	77	1	0	4	7	1	1	7
7/11/97	78	2	1	39	2	0	2	1	1	1	4
Total	2681	203	28	899	14	7	31	463	63	500	62

Trap catches indicated peaks of population within the season (Tables 9,10). The two bark beetle predators, *Thanasimus dubius* and *Temnochila virescens*, were most abundant in March and April; *T. dubius* declined rapidly in mid-April coinciding with the decline of the southern pine beetle. *Temnochila virescens* peaked in late March and remained at steady levels throughout July. Another peak in trap catches occured in early June dominated by *Ips* spp. (especially *Ips grandicollis*). *Ips*, the ambrosia beetle, *Platypus flavicornis*, and the black turpentine beetle, *Dendroctonus terebrans*, increased in numbers throughout the season until their peak in June, after which they steadily declined. Reproduction weevils, *Hylobius sp.* and *Pachylobius sp.* were collected in the funnel traps in greatest numbers from March 14 to May 9 (Table 9), then declined. Total phloem-feeding species peaked in March and April (Table 10). Of the total trap catch, 43 percent were bark beetle predators, 55 percent were phloem feeding insects, primarily bark beetles; and 2 percent were weevils. Of the bark beetle complex, southern pine beetle was most abundant through the April trappings and *Ips grandicollis* increased steadily through early June and declined into July (Table 10). Numbers of *Xyleborus* spp. peaked in April and early May. Unfortunately, southern pine beetle populations apparently peaked early this year, as what seemed to be the tail end of a peak in their populations was observed only in the first two of weeks of trapping. After this decline, their numbers did not rebound.

Table 9. Total phloem feeding insects versus predators by date.

Date	Reproduction Weevils	Total Phloem-Feeding Insects	Total Predators	Date	Reproduction Weevils	Total Wood-Boring Insects	Total Predators
3/14/97	45	915	1295	5/9/97	48	757	177
3/21/97	38	254	817	5/16/97	9	531	123
3/28/97	72	323	1943	6/6/97	8	2208	112
4/4/97	45	329	1311	6/27/97	5	638	74
4/18/97	7	118	233	7/4/97	4	612	62
4/25/97	45	590	334	7/11/97	3	433	48
5/2/97	12	848	130	Total	341	8556	6659

Table 10. Total catch of six traps of phloem and wood-boring insects and their insect predators by date.

Date	Total Insects	*Dendroctonus frontalis*	*Ips avulsus*	*Ips grandicollis*	*Ips calligraphus*	*Dendroctonus terebrans*	*Platypus flavicornis*	*Xyleborus sp.*	*Thanasimus dubius*	*Temnochila virescens*
3/14/97	2370	621	0	20	0	14	26	234	1250	45
3/21/97	1195	167	0	37	4	1	6	39	790	27
3/28/97	2442	142	0	80	7	3	5	86	1727	216
4/4/97	1780	98	0	166	1	0	2	62	1114	197
4/18/97	469	40	0	62	5	0	0	11	212	21
4/25/97	1209	116	0	255	5	1	0	213	228	106
5/2/97	1211	60	55	458	8	0	6	261	101	29
5/9/97	1262	55	44	315	2	4	50	287	120	57
5/16/97	813	23	20	336	6	1	30	115	97	26
6/6/97	2600	13	21	2096	2	0	49	27	37	75
6/27/97	986	27	4	582	7	1	7	10	12	62
7/4/97	918	7	4	558	19	0	12	12	11	51
7/11/97	773	8	1	390	20	0	3	11	6	42
Total	18028	1377	149	5355	86	25	196	1368	5705	954

Nantucket Pine Tip Moth

Although the models by White et al. (1984) and Wilson (1984) for hazard rating NPTM applied were not adequate for this study area, there were scattered areas of pine regeneration where Nantucket pine tip moth infestations were noticeable (Table 11, Fig. 3).

Percent infestation varied by site conditions and part of the tree sampled (Table 12). Terminal bud infestation varied from 20 to 55 percent infestation indicating a high infestation for the leader of the tree. Top whorl infestations varied from 0 to 23.2 percent. The top one-half of the pines showed infestations ranging from 3.3 to 33.2 percent. The bottom one-half of the pine had from 0 to 16.1 percent infestations. Lower infestation rates in the bottom half of the tree are typical. Higher infestations in the terminal and the top whorl generally indicated higher infestations in the total tree and in the total sample line (Anderson et al., 1984, White et al., 1984). Percentage of total tips infested ranged from 3.5 to 25.6 over the sample lines.

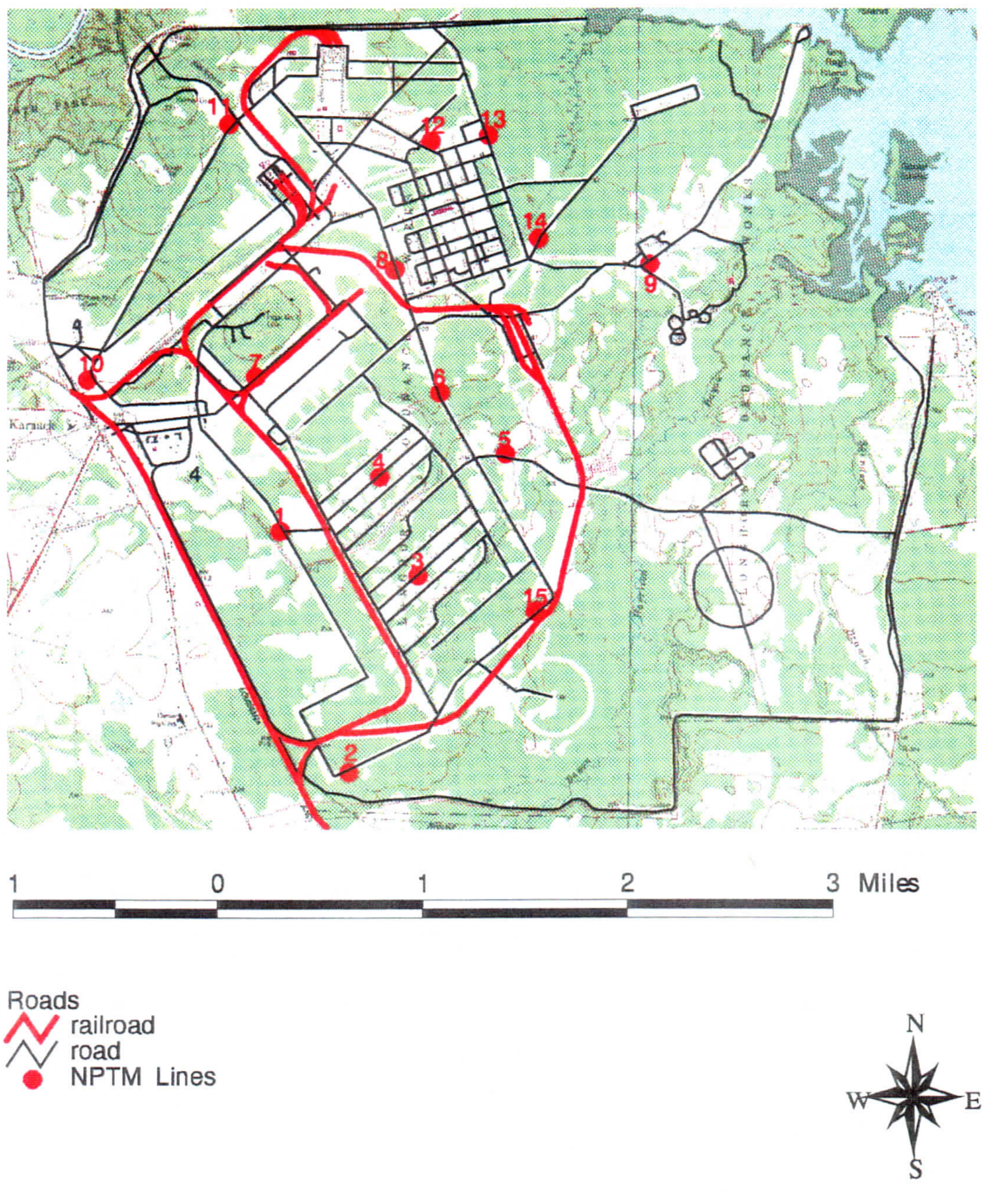
Table 11. Percent infestation of tips per section of pine regeneration by Nantucket pine tip moth at Longhorn Army Ammunition Plant. Twenty trees per line were sampled.

	Terminal Bud	**Top Whorl**		**Top Half**		**Bottom Half**			
Line	Percent Infested Tips	Number of Tips	Percent Infested Tips	Number of Tips	Percent Infested Tips	Number of Tips	Percent Infested Tips	Total Tips	Percent Total Tips Infested
1	30	63	11.1	114	8.7	139	5.7	336	9.2
2	35	56	1.7	71	2.8	138	0.0	285	3.5
3	40	74	8.1	106	5.6	147	1.3	347	6.3
4	50	69	4.3	131	13.7	170	2.9	390	9.2
5	55	56	23.2	77	31.1	93	16.1	246	25.6
6	40	60	20.0	50	14.0	97	10.3	227	16.3
7	35	56	8.9	59	22.0	88	10.2	223	15.2
8	40	56	17.8	79	20.2	84	14.2	239	19.2
9	20	56	12.5	65	16.9	91	10.9	232	13.7
10	40	58	15.5	57	7.0	76	13.1	211	14.6
11	20	42	9.5	50	0.0	79	2.5	191	5.2
12	20	51	21.5	69	18.8	78	15.3	218	18.3
13	40	51	11.7	40	25.0	84	5.9	195	14.8
14	30	49	8.1	50	12.0	87	12.6	206	13.1
15	30	50	0.0	61	3.2	75	6.6	206	6.3
Average	35.0	56.4	11.6	71.9	13.4	101.7	8.5	250.1	12.7

Table 12. Total Nantucket Pine Tip moth infestation rates per line, soil (Tables 15,16) and site conditions above and below the mean infestation rate of approximately 12.47.

Line	Soil	Site	Percent Total Tips Infested	Total Tips
Below Average Infestation				
2	McA	shaded, wet	3.51	285
11	EaC	shaded, wet	5.24	191
15	EaE	shaded, wet	6.31	206
3	SvA	shaded, wet	6.34	347
Average			5.35	257.25
Average Infestation				
1	McA	half-shade, wet	9.23	336
4	SvA	shaded, wet	9.23	390
14	SvA	half-shade, wet	13.11	206
9	SvA	sunny, wet	13.79	232
10	LeB	sunny, wet	14.69	211
13	SvA	sunny, wet	14.87	195
Average			12.49	261.67
Above Average Infestation				
7	SvA	sunny, dry	15.25	223
6	SvA	sunny, dry	16.3	227
12	SvA	sunny, wet	18.35	218
8	SvA	sunny, wet	19.25	239
5	EaC	sunny, dry	25.61	246
Average			18.95	230.60

Figure 3. Locations of the transect lines used to sample for Nantucket pine tip moth at Longhorn Army Ammunition Plant.



Fusiform Rust

The ten study plots were used to sample for incidence of fusiform rust within the military installation (Figs. 6-16). Within the plots, percent of the plot and percent of the stand infected with fusiform rust were recorded. Mortality due to fusiform rust was low although there was a high incidence of the disease in the plots (Table 13). Though there does not appear to be a relationship in this case to tree height or dbh or stand basal area, site conditions do appear to have a role in the infection rate (Table 14).

Table 13. Percent infection of pine stands by fusiform rust at Longhorn Army Ammunition Plant.

Stand Number	Plot Number	Percent Plot Fusiform	Percent Stand Fusiform	Percent Plot Mortality
1	1	23	28	
1	2	22		
1	3	20		
1	4	46		
2	1	56	31	
2	2	7		
3	1	55	43	
3	2	17		
3	3	63		
3	4	40		10
4	1	47	48	
4	2	50		
5	1	0	14	
5	2	0		
5	3	23		
5	4	33		
6	1	79	79	
7	1	0	0	
7	2	0		
7	3	0		
7	4	0		
8	1	8	4	
8	2	0		
9	1	30	14	
9	2	0		
9	3	13		
9	4	11		
10	1	40	37	
10	2	33		

Table 14. Fusiform rust incidence and location on tree with regard to site characteristics.

Stand	Stand Description	Average Height	Average Dbh	Average BA/Acre	Percent Stand Fusiform	Percent Total branch > 15"	Percent Total stem	Percent Total branch < 15"	Percent Total Mortality
1	wet, moderate understory, large pine with few hardwoods	85.8	15	113	28	84.6	15.3	0	0
2	wet, dense understory, medium pine with few hardwoods	62.8	13	115	31	33.3	50	16.6	0
3	moist, sparce understory, large pine	76.5	16	103	43	50	44.4	5.5	5.5
4	moist, no understory, medium pine	60.9	11	145	48	35.7	28.5	35.7	0
5	moist, sparce understory, small, malshaped pine	38.3	7	125	14	28.5	71.4	0	0
6	moist, medium understory, dense, pine regeneration	32.4	5	140	79	54.5	0	45.4	0
7	dry, medium understory, large, scattered pine	73.8	19	63	0	0	0	0	0
8	moist, dense understory, medium pine with few hardwoods	54.1	11	115	4	0	100	0	0
9	wet, sparce understory, large pine-hardwood mix	72.8	17	108	14	0	100	0	0
10	moist, sparce understory, medium pine	62.2	13	165	37	0	100	0	0

Annosus Root Rot

Hazard rating for annosus root rot based on soil and site characteristics indicated potential areas for infection, but ground checking of field plots failed to detect direct evidence of the disease (Figs. 4,5, Tables 15-17). Older openings in the stand may indicate old infection centers as do the presence of stump holes, but no indications of the disease in the form of conks or resinosus at the roots were present within the current stand. Careful monitoring of stands following thinnings is encouraged in areas of higher hazard for annosus root rot.

Table 15. Soils occuring within boundaries of Longhorn Army Ammunition Plant and their characteristics.

Soil Name Abbreviation	Soil Name	pH (low)	pH (high)	pH (Average)	Available Water	Drainage
Cy	Cypress clay loam, submerged	3.6	5.0	4.3	high	very poorly drained
EaC	Eastwood very fine sandy loam, 1 to 5% slopes	3.6	7.3	5.5	high	moderately well drained
EaE	Eastwood very fine sandy loam, 5 to 20% slopes	3.6	7.3	5.5	moderate	moderately well drained
EcA	Erno-Cart complex, 0 to 2% slopes	4.5	6.5	5.5	moderate	well drained
GcA	Guyton-Cart complex, 0 to 1% slopes	3.6	8.4	6.0	high	poorly drained
Iu	Iuka fine sandy loam, frequently flooded	4.5	6.0	5.3	moderate	moderately well drained
LeB	Latex fine sandy loam, 1 to 3% slopes	3.6	6.0	4.8	high	well drained
McA	Metcalf - Cart complex, 0 to 2% slopes	4.5	6.0	5.3	high	somewhat poorly drained
MeB	Meth fine sandy loam, 1 to 3% slopes	4.5	6.5	5.5	high	well drained
Sm	Sardis-Mathiston complex, frequently flooded	4.5	6.0	5.3	high	somewhat poorly drained
SvA	Scottsville very fine sandy loam, 0 to 2% slopes	4.5	6.0	5.3	very high	moderately well drained
Sz	Socagee silty clay loam, frequently flooded	3.6	7.3	5.5	high	poorly drained
WoC	Wolfpen loamy fine sand, 2 to 5% slopes	4.5	6.5	5.5	moderate	well drained
WoE	Wolfpen loamy fine sand, 8 to 15% slopes	4.5	6.5	5.5	moderate	well drained

Table 16. Proportions of soils within Longhorn Army Ammunition Plant.

Soil Name Abbreviation	Soil Present in Study Area (Acres)	Soil Present in Study Area (Percent)
Cy	55.7	0.67
EaC	956.8	11.5
EaE	333.1	4.0
EcA	41.4	0.5
GcA	208.5	2.5
Iu	277.7	3.3
LeB	203.8	2.4
McA	974.9	11.7
Meb	65.2	0.8
Sm	312.4	3.8
SvA	3992.4	48.0
Sz	856.6	10.3
Water	6.6	0.1
WoC	2.4	0.0
WoE	29.7	0.4

Table 17. Annosus root rot hazard rating based on soils occuring within boundaries of Longhorn Army Ammunition Plant and some soil characteristics.

Soil Name Abbreviation	pH (low)	pH (high)	pH (Average)	Available Water	Drainage	Annosus Root Rot Rating
Cy	3.6	5.0	4.3	high	very poorly drained	minimal
EaC	3.6	7.3	5.5	high	moderately well drained	low
EaE	3.6	7.3	5.5	moderate	moderately well drained	moderate
EcA	4.5	6.5	5.5	moderate	well drained	high
GcA	3.6	8.4	6.0	high	poorly drained	low
Iu	4.5	6.0	5.3	moderate	moderately well drained	moderate
LeB	3.6	6.0	4.8	high	well drained	low
McA	4.5	6.0	5.3	high	somewhat poorly drained	low
MeB	4.5	6.5	5.5	high	well drained	moderate
Sm	4.5	6.0	5.3	high	somewhat poorly drained	low
SvA	4.5	6.0	5.3	very high	moderately well drained	minimal
Sz	3.6	7.3	5.5	high	poorly drained	low
WoC	4.5	6.5	5.5	moderate	well drained	high
WoE	4.5	6.5	5.5	moderate	well drained	high

Figure 4. Delineation of soils occuring at Longhorn Army Ammunition Plant.

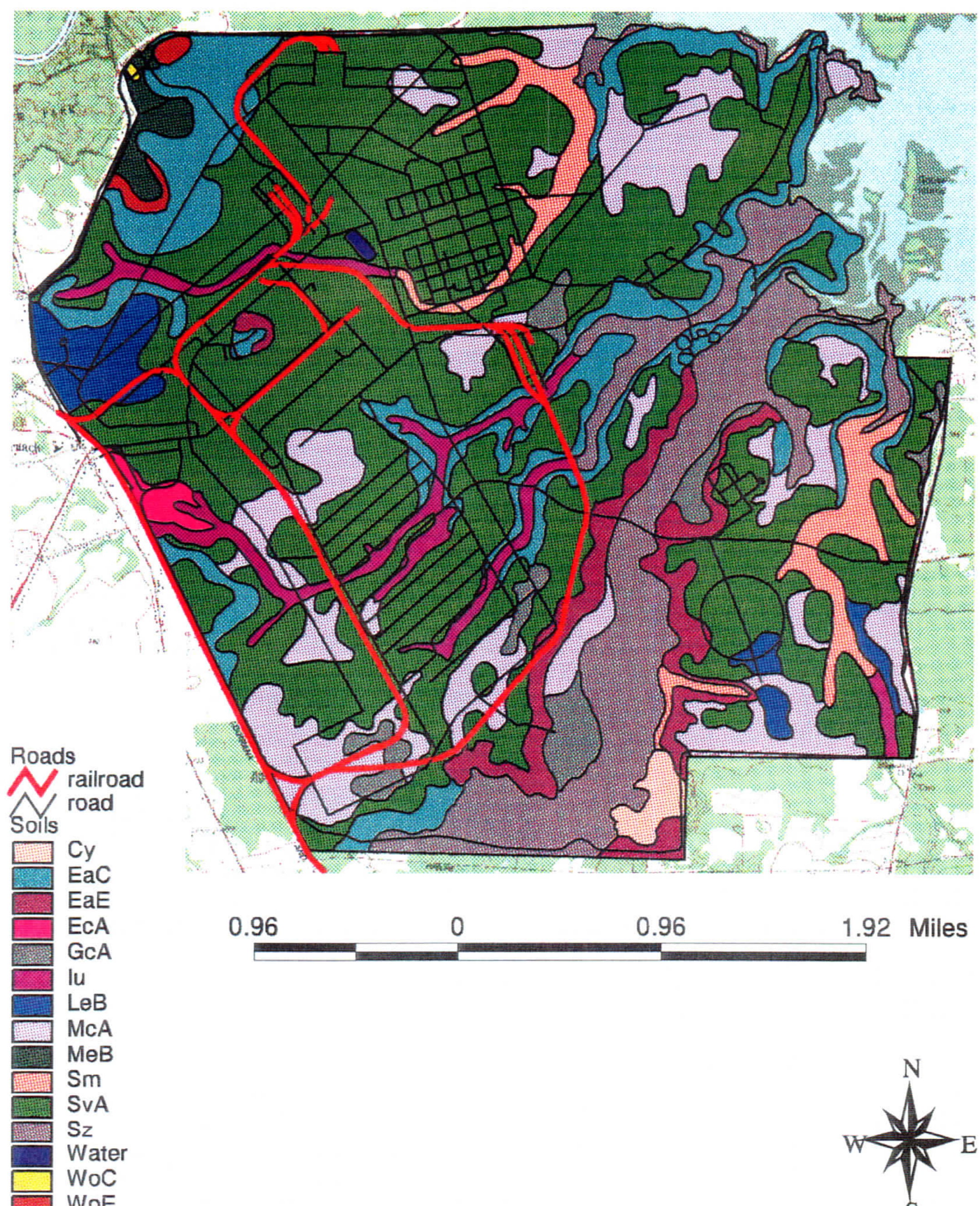
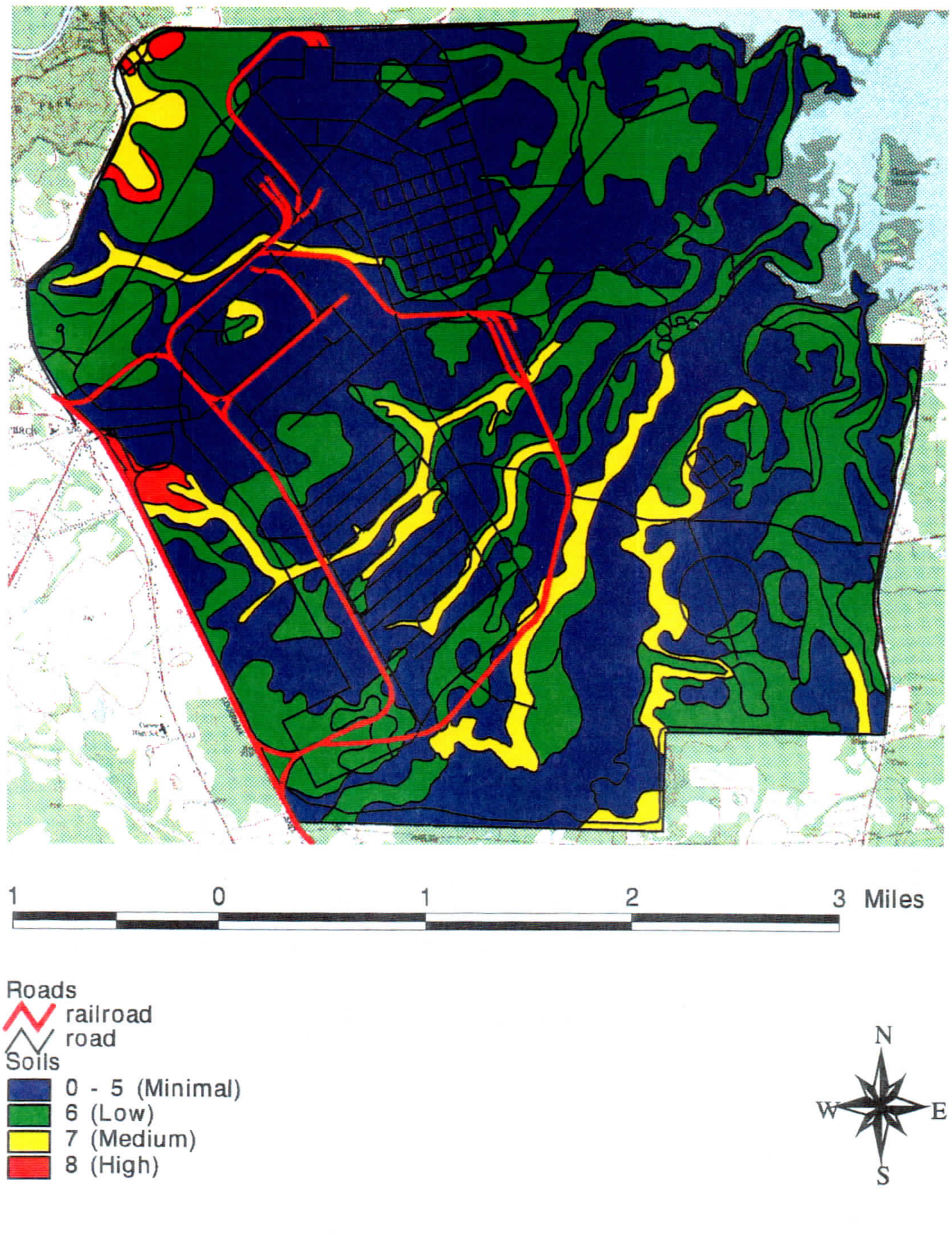


Figure 5. Annosus root rot risk rating based on soil characteristics at Longhorn Army Ammunition Plant.



Aerial Videography

Estimations of site factors needed to hazard rate the pine stands for SPB were taken from video mosaics and other data derived from the GIS (Figs. 6-16). The field results were then matched against the estimates (Tables 18,19). An examination of basal area estimates ranged from a difference of 0 to 50 basal area of pine (Table 18). Four stands were underestimated from 5 to 28 square feet basal area, one was estimated exactly, and 6 were overestimated from 5 to 50 square feet basal area. Comparing the actual to estimated basal area indicated only 1 of the 10 stands were classified incorrectly (Table 19).

Table 18. Comparison of BA/Acre as estimated from aerial videography versus field measurements.

Stand	Plot Number	Est. BA using ArcView	Est. Total BA	Actual BA	Total BA/Ac.	Error in BA Estimate/Plot	Error Stand BA Est.
1	1	100	85	130	113	-30	-28
	2	100		90		10	
	3	80		100		-20	
	4	60		130		-70	
2	1	110	120	90	115	20	5
	2	130		140		-10	
3	1	80	108	110	103	-30	5
	2	150		120		30	
	3	110		80		30	
	4	90		100		-10	
4	1	150	145	150	145	0	0
	2	140		140		0	
5	1	120	115	140	125	-20	-10
	2	130		110		20	
	3	110		130		-20	
	4	100		120		-20	
6	1	190	190	140	140	50	50
7	1	70	50	90	63	-20	-13
	2	50		60		-10	
	3	50		70		-20	
	4	30		30		0	
8	1	130	135	130	115	0	20
	2	140		100		40	
9	1	110	103	100	108	10	-5
	2	120		90		30	
	3	110		150		-40	
	4	70		90		-20	
10	1	180	190	150	165	30	25
	2	200		180		20	
Total						-50	50

Table 19. Comparison of pine hazard rating results using estimated values of height and BA/Acre versus field measured values.

Stand	Estimated Height	Actual Ave. Ht.	Landform	Est. Total BA/Acre	Actual Total BA/Acre	Actual SPB Hazard Rating Mason	Estimated SPB Hazard Rating Mason	Difference
1	70	85.8	side slope	85	113	moderate	moderate	no
2	57	62.8	bottom	120	115	moderate	moderate	no
3	57	76.5	side slope	108	103	moderate	moderate	no
4	46	60.9	side slope	145	145	high	high	no
5	42	38.3	bottom	115	125	moderate	moderate	no
6	32	32.4	bottom	190	140	moderate	moderate	no
7	70	73.8	ridge	50	63	very low	very low	no
8	57	54.1	bottom	135	115	moderate	very high	yes
9	70	72.8	bottom	103	108	moderate	moderate	no
10	57	62.2	side slope	190	165	high	high	no

Figure 6. Location of the ten permanent study plots at Longhorn Army Ammunition Plant

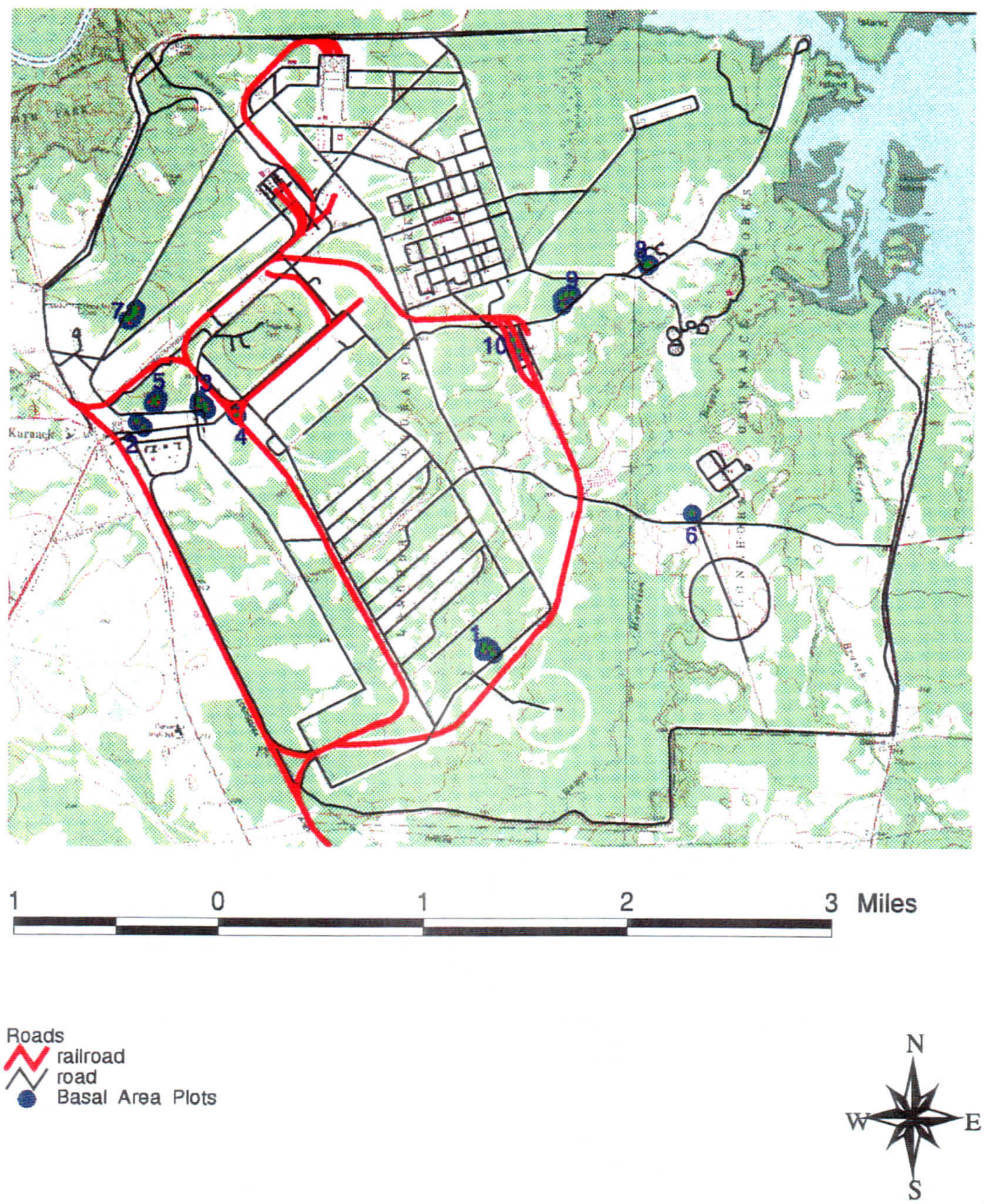


Figure 7. Study plot number 1 at Longhorn Army Ammunition Plant shown with aerial videography mosaic. Numbers in red indicate basal area.

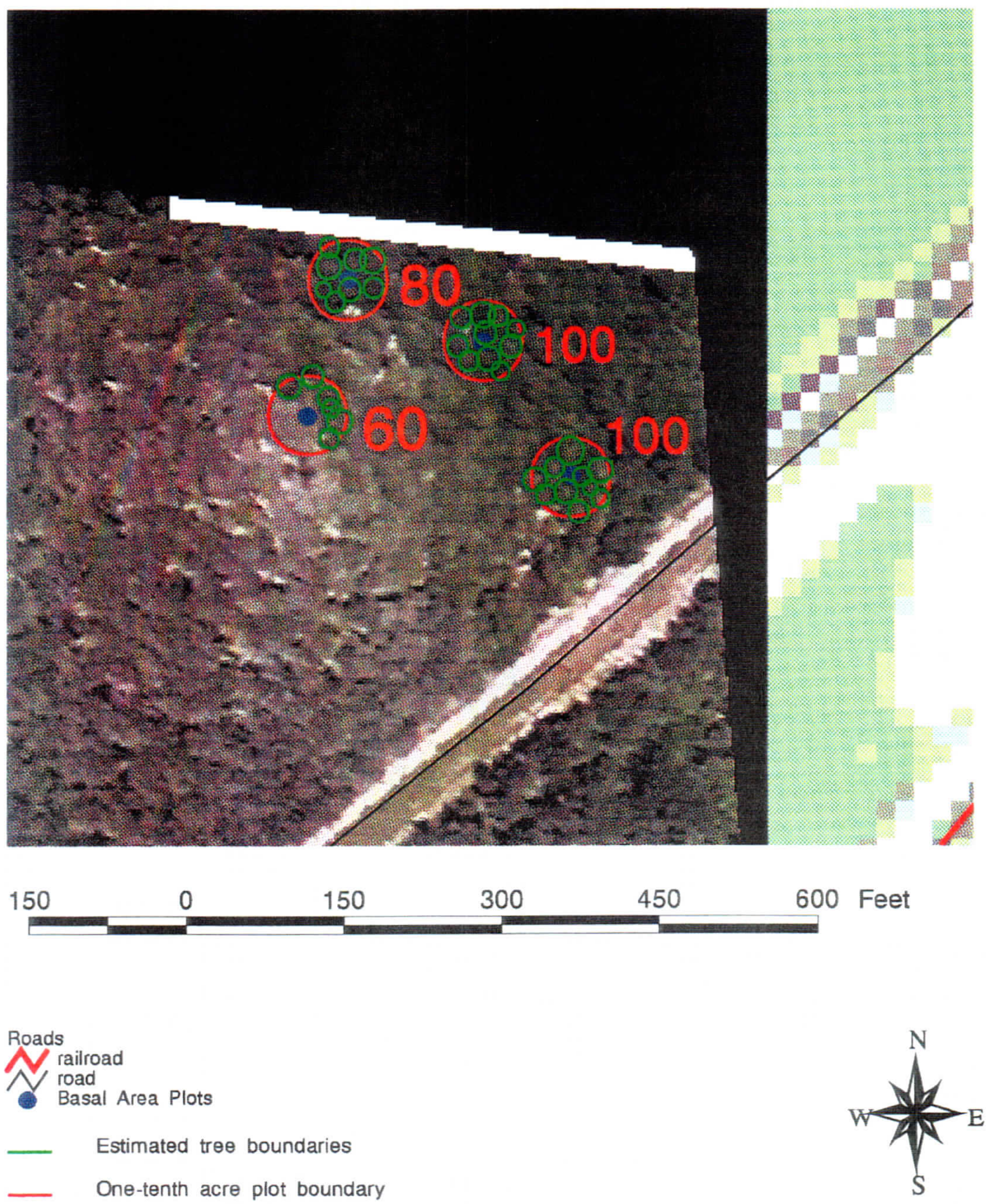


Figure 8. Study plot number 2 at Longhorn Army Ammunition Plant shown with aerial videography mosaic. Numbers in red indicate basal area.

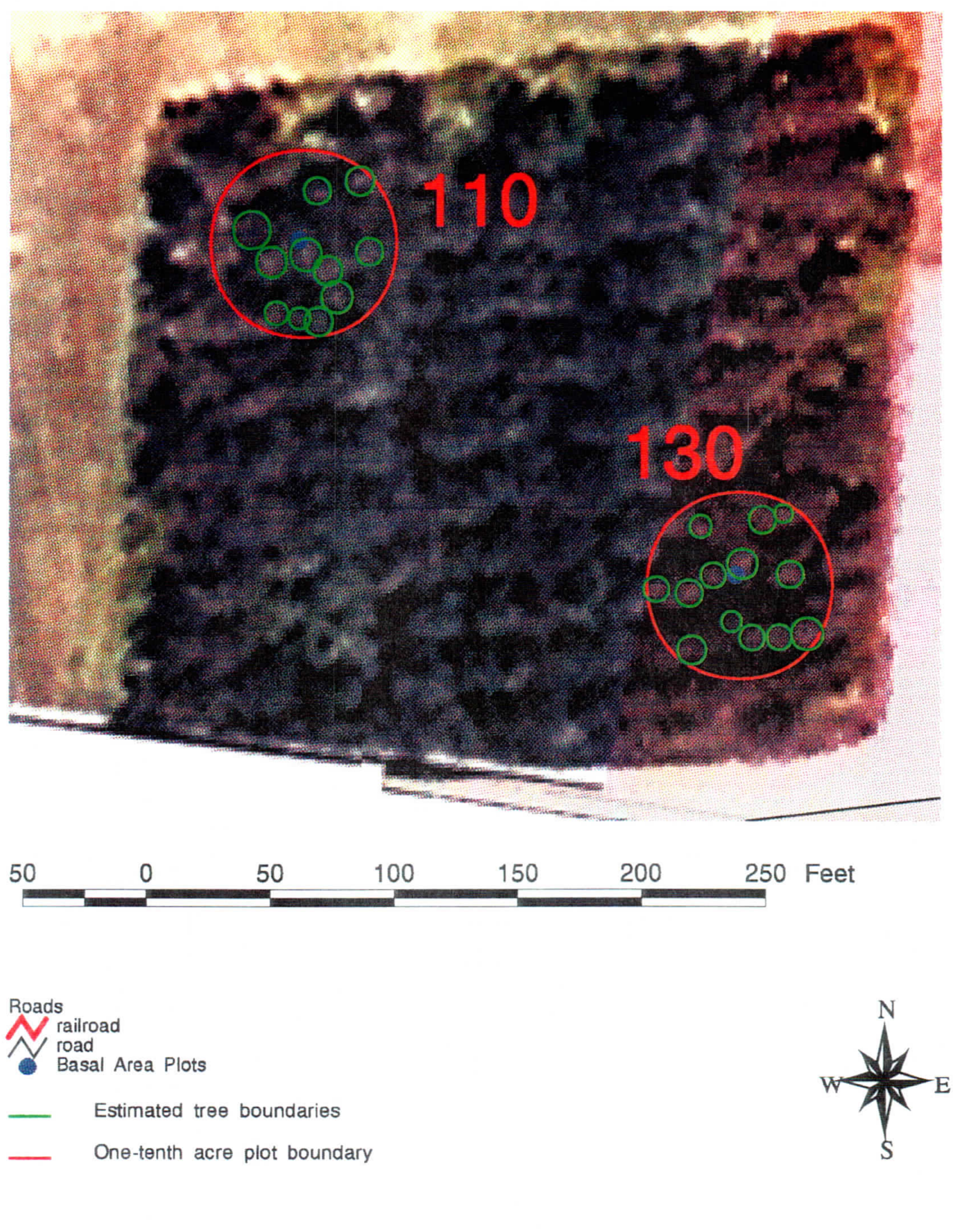


Figure 9. Study plot number 3 at Longhorn Army Ammunition Plant shown with aerial videography mosaic. Numbers in red indicate basal area.

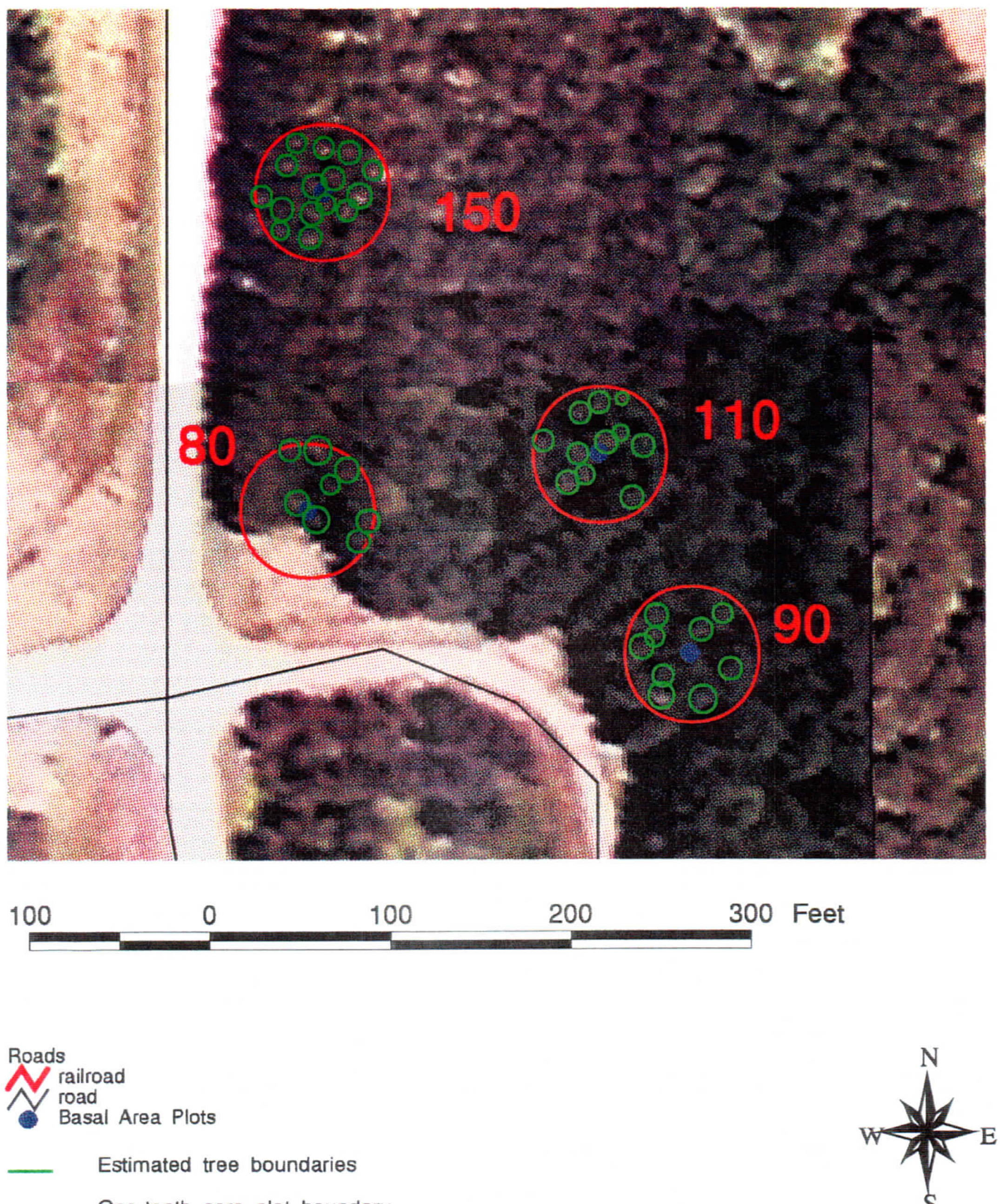


Figure 10. Study plot number 4 at Longhorn Army Ammunition Plant shown with aerial videography mosaic. Numbers in red indicate basal area.

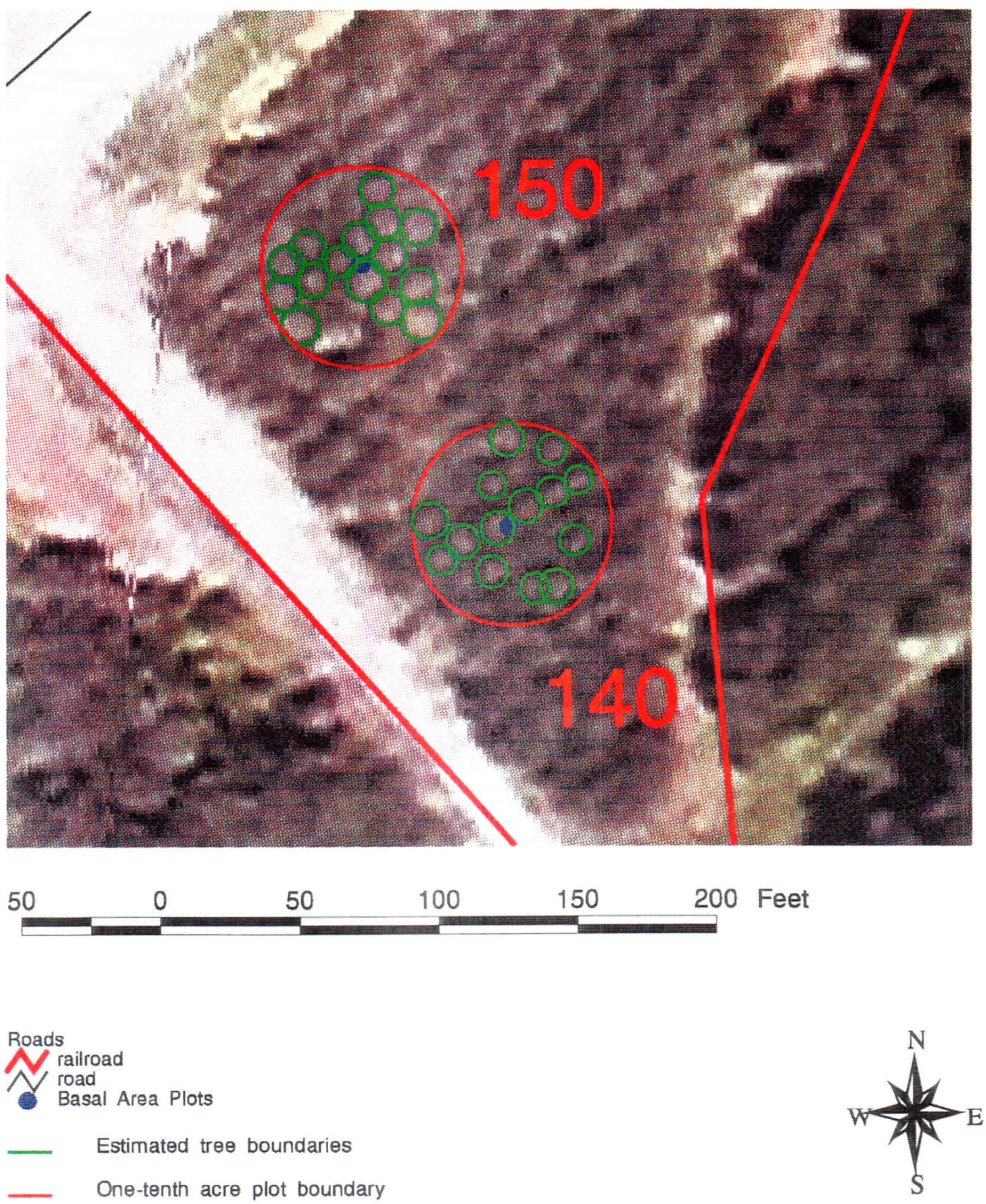


Figure 11. Study plot number 5 at Longhorn Army Ammunition Plant shown with aerial videography mosaic. Numbers in red indicate basal area.

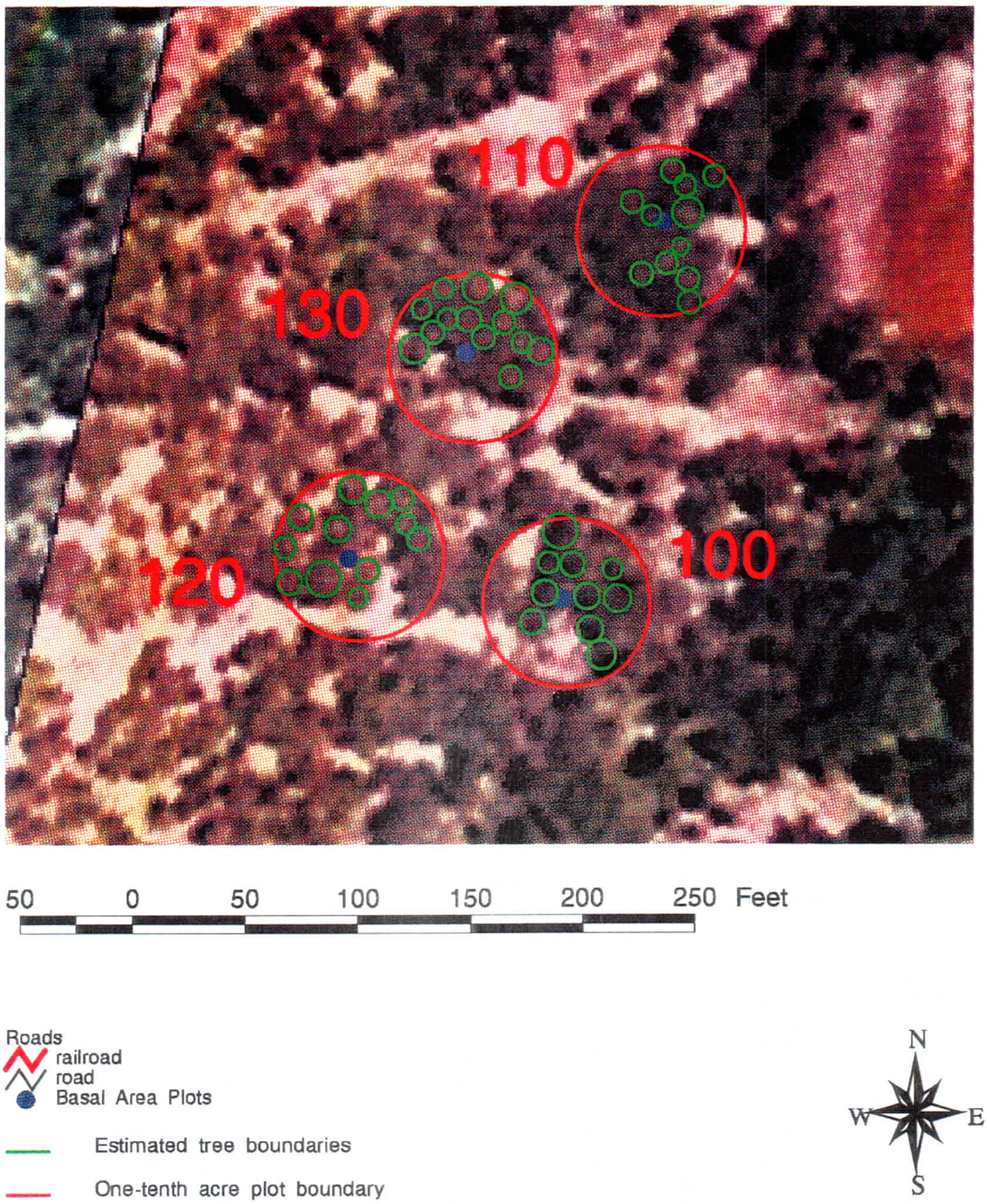


Figure 12. Study plot number 6 at Longhorn Army Ammunition Plant shown with aerial videography mosaic. Numbers in red indicate basal area.

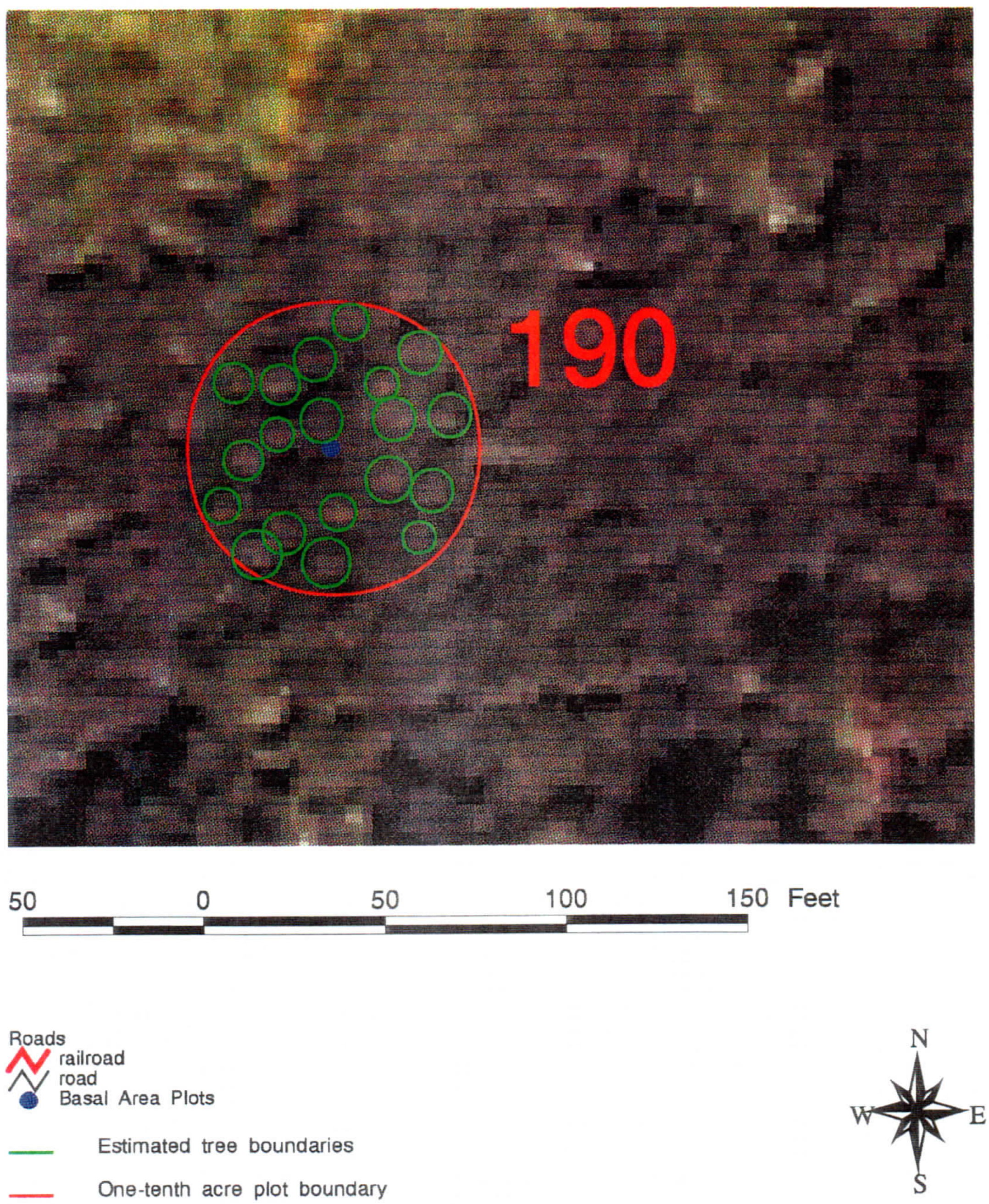


Figure 13. Study plot number 7 at Longhorn Army Ammunition Plant shown with aerial videography mosaic. Numbers in red indicate basal area.

Figure 14. Study plot number 8 at Longhorn Army Ammunition Plant shown with aerial videography mosaic. Numbers in red indicate basal area.

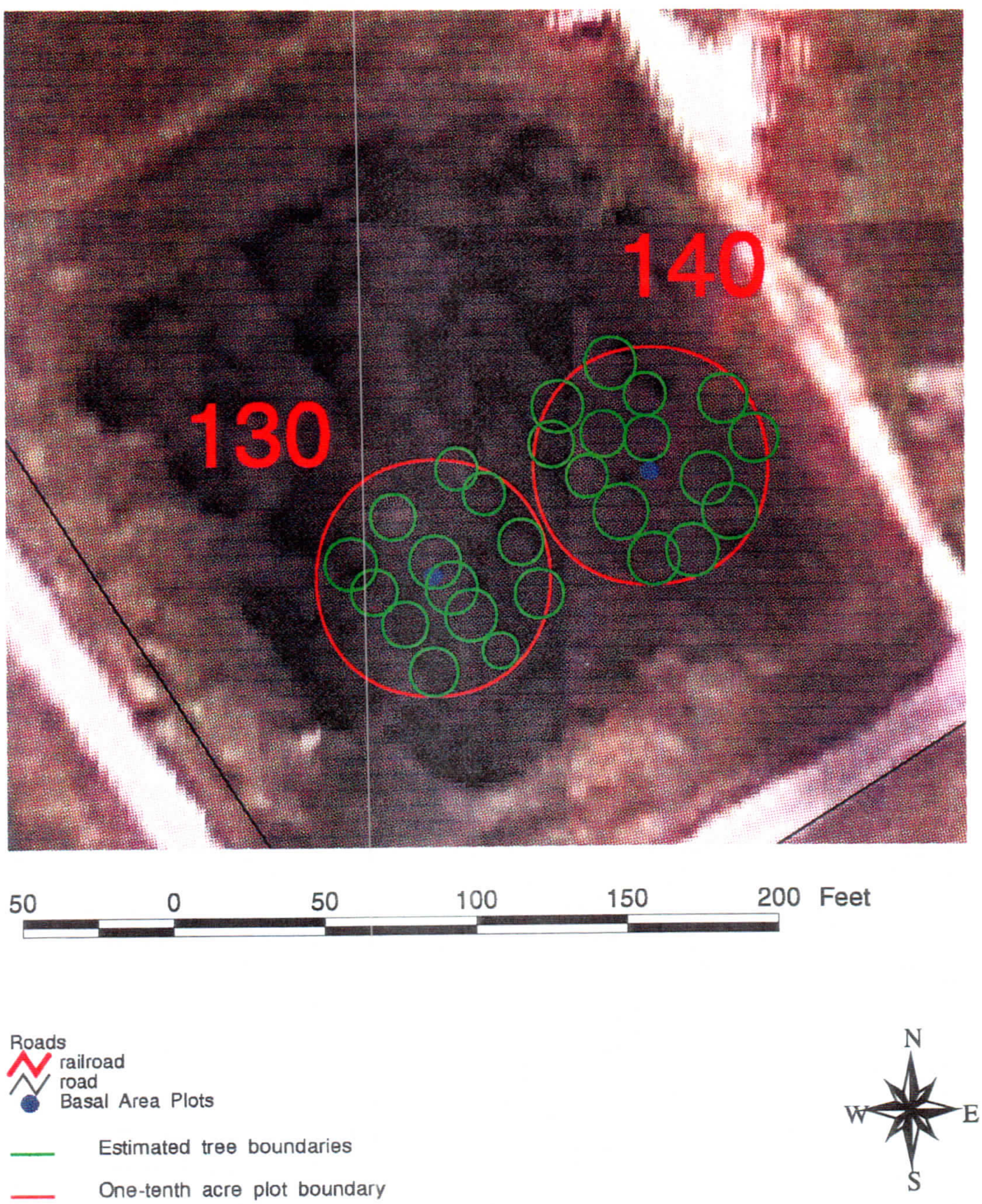


Figure 15. Study plot number 9 at Longhorn Army Ammunition Plant shown with aerial videography mosaic. Numbers in red indicate basal area.

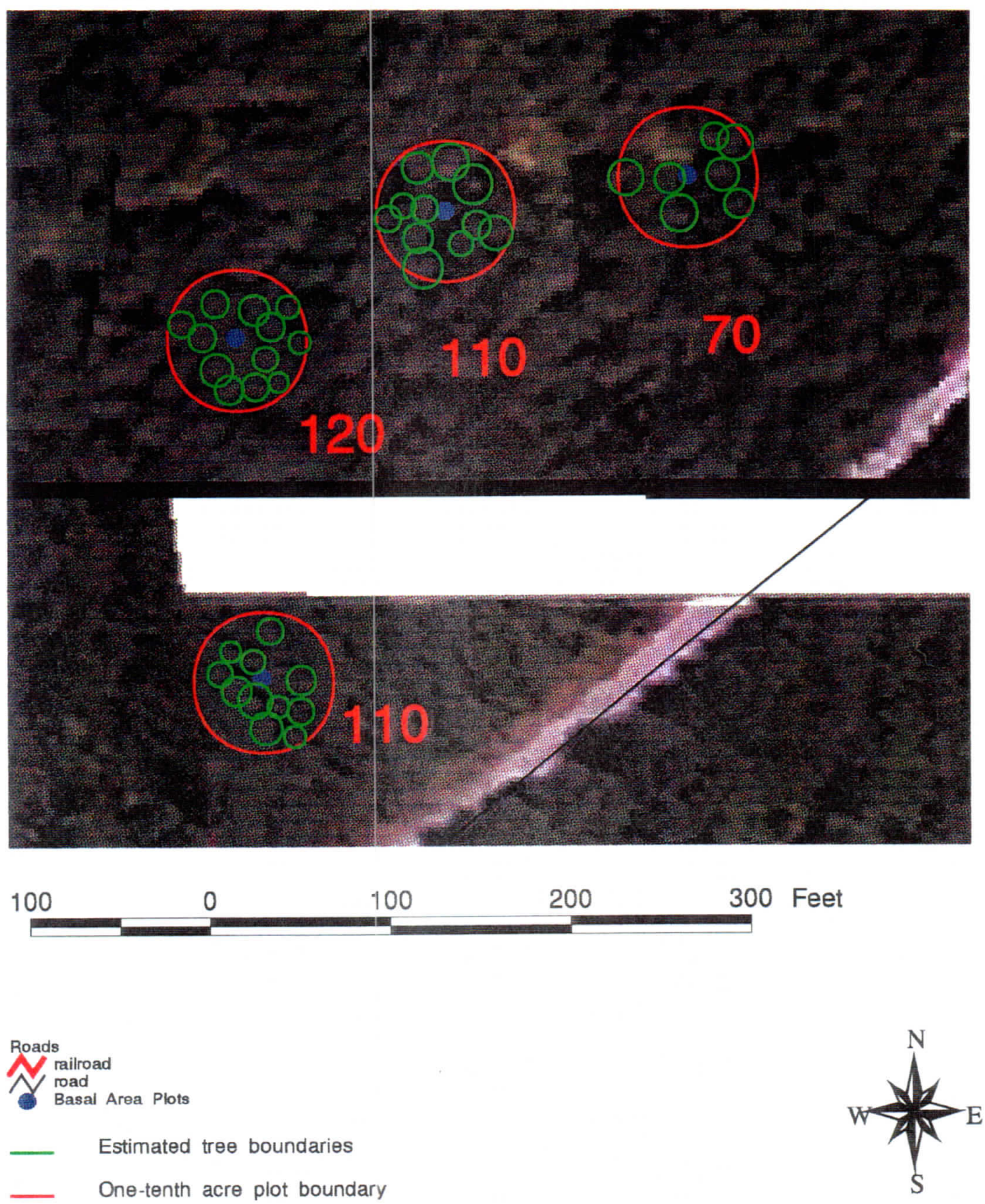
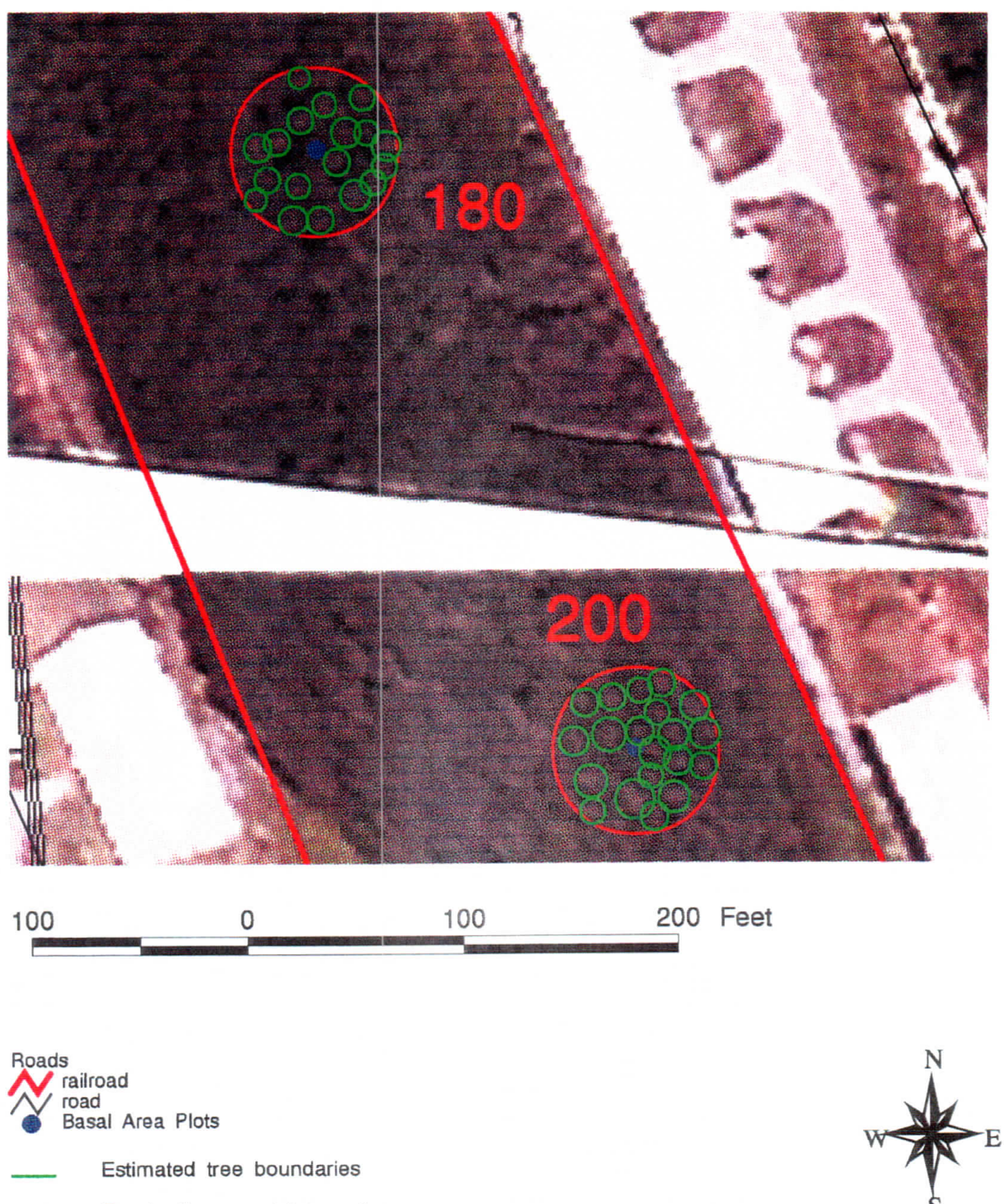


Figure 16. Study plot number 10 at Longhorn Army Ammunition Plant shown with aerial videography mosaic. Numbers in red indicate basal area.



DISCUSSION

Southern Pine Beetle

The discrepancy between the prediction models and the actual trap catch is probably due to 1) the relatively light year for SPB populations, and 2) the large hardwood component of stands located in and around the study area, though the study was aimed at stands consisting of mostly or only pine. The pattern demonstrated in Tables 3-8 indicates that SPB and *Ips spp* peak at different times of the year. The SPB predators *Thanasimus dubius* and *Temnochila virescens* followed trap catches of the SPB. These two beetles did not respond to the peak in the *Ips spp* population or were not attracted to the *Ips* pheromone traps.

Catches indicate reasonably consistent counts between the traps over the collecting period (Tables 3-8). Within trap 3, numbers of *Ips* beetles were much higher than predator catches, indicating that this trap may have been located near an *Ips* bark beetle infestation (Fig. 2). Predators peaked in traps 1 and 5, possibly following the slight peaks of the southern pine beetle in the same traps. Total populations are also highest in these two traps, possibly because of the trap locations within a mature pine stand as with trap 1, or directly outside a mature stand and a stand of pole-sized trees as with trap 5. Traps 4 and 2 had the lowest total insect count and were both located directly outside mixed pine-hardwood stands. Trap 3 was located outside a pole-sized stand with a dense understory in which the trees were highly susceptible to injury because of much human activity occuring in and around the stand with heavy equipment. Trap 6 was located outside a young pine stand which may have been resistant enough to discourage attack by bark beetles.

Nantucket Pine Tip Moth

Areas of lower and average infestations of Nantucket pine tip moth (Fig. 3, lines 1-4, 9-11, 13-15) were in areas of older pines and the pine regeneration was not as prolific. These areas were in heavy shade much of the day from the overstory canopy. Also these pines were in areas conducive to good health (especially in regard to water and soil conditions), which may have helped prevent or aided in the recovery from attacks by NPTM.

Sample lines 5, 6, 7, 8, and 12 had the highest infestations, ranging from 14.7 to 25.6 percent (Table 12, Fig. 3). Higher infestations occurred in open, sunny areas under powerlines and in recently disturbed areas. In comparison to other, less infested sites, the pines here were visibly stunted and chlorotic from lack of health and/or previous attacks. NPTM infestations generally did not present a problem in stands not managed for early commercial value. As the stands mature, infestations generally diminish.

Fusiform Rust

The results of the study indicate a high incidence of fusiform rust throughout the stands with infection rates ranging from 0-79% (Table 13), with the average infection rate for the ten stands being 29.8%. Stands 7 and 8 had very low incidence of the disease. Stand 8 is an island surrounded by buildings and roads. It is possible that the distance to the nearest tree within the surrounding stands was far enough away so that the sporidia could not reach the stand or that not enough were able to reach the stand to be able to make the chance landing on the required substrate. Stand 7 consisted of very large mature pine thinned and with little or no mid- or under-story. If any fusiform was present in the trees of this stand, it was not evident. The cause for the low incidence here was probably the sheer size of the trees. Stand 6 had the highest infestation (79%) of fusiform rust. This stand was a very dense, young pure stand of pine which was surrounded by water oak. This stand provided the disease with enormous opportunity for development. Despite the high infection rate of the pine, there was a low incidence of fusiform-caused mortality. Many of the trees, especially in Stand 6, were gnarled and otherwise very unhealthy looking. Numerous windsnaps were observed, though outside of the sampling population. The areas rated high hazard or having a high infection rate should be examined closely and a plan for future use of the pine may be developed in order to appreciate what must be done to achieve the goal or goals of the stand in light of the heavy incidence of the disease. The low mortality rate may be misleading, as death is not the only damage that the disease causes. Severe degrade and wood loss may occur in infected trees.

Conclusions

Hazard rating for bark beetles, Nantucket pine tip moth, annosus root rot, and fusiform rust were completed on the Longhorn Army Ammunition Plant. Stands were generally rated as moderate for southern pine beetle; moderate to high infestations of pine tip moth occurred with little associated damage; and annosus root rot was not apparent in the stands. Fusiform rust was evident in the stands but little mortality occurred. Aerial videography at 1,000 feet AGL is adequate for Southern pine beetle hazard rating. Because of the relative low resolution of video, missions need to be flown at about 1000 feet above ground level (AGL) before individual trees in a dense forest can be discerned. Missions such as this should probably only be used for small stands, such as for red-cockaded woodpecker, *Picoides borealis*, stands, military installations, or tree farms. However, if a general small-scale overview of a large area is all that is needed, video would be a good choice because of its cost and time efficiency. Estimations of hazard for southern pine beetle based on landform, basal area, and height of the dominant pines based on Mason et al. (1981) indicated the adequacy of this method for hazard rating using aerial videography flown at 1000 feet AGL (Tables 18,19). The incorporation of the study data into a GIS greatly aids the user in interpreting current conditions at the LAAP. Geographic information systems may be a very useful tool for, but not limited to, natural resource managers to better perform their job through an easily used and interpreted method of displaying data. Moreover, the GIS allows the manager to easily communicate the data to other people because of its graphical interface.

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